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Final Report

VALIDATION OF THE DEI TECHNIQUE FOR LARGE-SCALE DISPLAY EVALUATION

Arthur I. Siegel
Philip J. Federman
Applied Psychological Services

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FOREWORD

This final report was prepared by Applied Psychological Services, Science Center, 404 East Lancaster Avenue, Wayne, Pennsylvania, under Contract AF30(602)-4056, Project 5597, Task No. 559705. Authors were Arthur I. Siegel and Philip J. Federman.

Acknowledgement is due a number of others who have made both scientific and technical contributions to the work reported here. At Applied Psychological Services, William Miehle and Harold Platzer provided certain of the analytic techniques employed, and Randall Ruch performed a number of the statistical analyses. Mr. Miehle was also highly instrumental in the original development of the Display Evaluative Index technique. Martin Metzler performed the art work involved in the development of the large scale display stimuli employed. Final typing and preparation of this report for publication were performed by Gail G. Rush and Estelle Siegel.

RADC Project Engineer was William J. Doherty. Both Mr. Doherty and R. J. Christman of the Display Techniques Branch, Rome Air Development Center, provided guidance throughout, and also made a number of constructive suggestions regarding data interpretation and research emphasis.

This technical report has been reviewed and is approved.

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ABSTRACT

The validity of the Display Evaluative Index technique was investigated in two separate studies. Both studies indicated adequate predictive validity for the technique. The ability of the technique to predict "decision-making" was found to be superior to its ability to predict "information extraction" processes. Generally, it was found that pictorial type displays are superior to tabular displays for "decision-making"; no difference seemed manifest between the two display types for "information extraction." Adding appropriate color coding seemed to augment the ability of the user to employ display information. As fact density increased, display decision-making scores decreased.

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EVALUATION

This study is one of several exploratory investigations directed to the perplexing and difficult problem of predicting the operational effectiveness of alternative or competing large-scale display designs. As one approach to the problem, the console-oriented Display Evaluative Index (DEI) was modified by its originators to provide a figure of merit based on decision adequacy rather than control action performance. The approach is consistent with our view that decision-making facilitation is the most important objective of good large-scale display designs.

Outstanding among several contributions made during the course of this investigation are:

a. The modified DEI shows considerable promise of being the most effective means presently available for assessing and predicting display performance. It should be noted, however, that application of such analytic procedures as the DEI must be limited to situations where the utilization requirements for displayed information are well defined.

b. Within the limitations of the experimental design, the data support the contention that information utilization, rather than information extraction, provides the most appropriate criterion for measuring operational effectiveness.

Encouraged by the results of this initial study, we plan to continue work toward refinement of the DEI technique. As part of the proposed study, a list of utilization factors will be prepared, together with new design principles, for the organization and presentation of displayed information. Performance tests will be conducted to determine the capability of the improved DEI to provide the link between decision adequacy and individual characteristics of display design.

William J. Doherty

WILLIAM J. DOHERTY
Project Engineer

CHAPTER I

INTRODUCTION

Developers and users of large-scale displays possess the requirement for evaluating these displays, from the information transfer point of view, while the displays are in the design proposal stages. Aside from various subjective evaluations, which have been and are being used extensively for evaluating displays, information presentation has also been analyzed previously from the points of view of individual parameters. For example, studies have been performed in such areas as character legibility, form, size, color, and information density. However, few techniques are available which employ objective measurement and calculational methods for evaluating large-scale displays.

The values of such an objective technique would be manyfold. Costly design errors might be avoided or minimized, the effectiveness of alternative display designs might be determined early in the development stages, and performance estimates for the man-machine integral could be derived while it is early enough to correct a failure to achieve system requirements.

The Display Evaluative Index (DEI)

Applied Psychological Services has developed a technique for quantitatively evaluating the ability of displays to transfer information to operators in a system, and for the operators to act on this information (Siegel, Miehle, and Federman, 1964). The technique is called the Display Evaluative Index (DEI) technique and yields a number which is said to represent a figure of merit for a given display. The DEI technique was drawn from a number of information transfer principles and has been applied to a number and range of military equipments, including command and control systems. The numerical value resulting from application of the DEI technique to a display is based on identifiable and measurable parameters. The technique, which has been validated, does not require experimental verification each time it is used. Freitag (1966), in reviewing the literature on man-machine hardware operability assessment, stated that where information transfer efficiency between a system and a human operator is concerned, an index such as the DEI may be all that is required. Specifically, Freitag maintained that "... of the presently available systematic attempts at definition, the most promising techniques were determined to be those utilizing information transfer concepts (Display Evaluative Index), empirical measurements (the s/n ratio), and the computerized technique (Monte Carlo and man-in-the-loop simulation)."

Principles Incorporated into DEI

In order to provide an index which possesses concept as well as empirical validity, the DEI was made to reflect a number of information transfer principles. The following conceptual principles are incorporated into the DEI technique. All else being equal, that system is best which:

1. requires the least operator information processing per subtask unit. For example, a predictive display is considered superior to a non-predictive display.

2. has the greatest directness between the information transmitters and the decisions. For example, as the number of nodes in a communications network increases, the efficiency of the network decreases and its vulnerability increases.

3. has the least difference between the amount of information presented and that required. For example, differential operator filtering and/or amplification may serve to increase error potential and decrease information transfer effectiveness.

4. provides for redundancy of information. For example, a message can be decoded quicker and with fewer errors when it contains redundant information.

5. requires the least intermediate data processing by the operator before he can reach a decision. For example, unit conversions, transformations and the like, serve to delay information transfer and to introduce error potential.

6. has the least number of information sources. For example, Kaufman and Kaufman (1960) suggest that the error potential of a system increases as its size and volume (number of components) increases.

The aspects, enumerated above, are represented by factors which vary from zero to one. A factor has the value of one when the system is "perfect"

with respect to that factor. The DEI is the product of all factors involved, each suitably weighted by means of an exponent. The results of the multiplication is that the DEI also varies between zero and one. The implication of the multiplicative form is that "a chain is as strong as its weakest link." An alternative additive form would take each factor as a term with an appropriate coefficient. In this case, the effect of any factor with a very low rating would be absorbed or hidden by other factors with higher ratings. This is minimized in the form adopted. No claim is made that a single numerical value of the DEI will indicate the absolute merit of a particular display. Rather, the DEI values of alternative displays will rank the designs along a continuum representing information transfer effectiveness.

Use of the DEI Technique

In applying the DEI technique, a transfer chart, representing the information transfers involved in a given display reading $\longrightarrow$ information processing $\longrightarrow$ control action set, is first drawn. This constitutes a major step in the analysis of the display and the decisions or control actions to be made.

Transfer of information between the display and the decision is indicated by a link (line) between the two. If intermediate data processing is required, this is represented by a box inserted in the link (creating a total of two links). If information from two or more information sources is required for making a decision, an "and" gate symbol, , is used to connect the information source and the specific decision. If a decision is made on the basis of one out of several indicators of information, an "or" symbol, , is used in the link between the indicator and the decision.

The transfer chart is not a flow chart; it is more like a time exposure in which repeated actions do not produce additional lines or links. The transfer chart serves as the basis for calculating each of the factors used in the DEI. A typical transfer chart, drawn in this study, is presented in Appendix F to this report.

Factors in the DEI

The complexity factor, involving principles 1 and 4 above, relates to the complexity of the information transfers involved. Each link is assigned a weight according to its complexity. A box possesses a link weight of four while other link weights vary between zero and two. The rationale for the derivation of the link weights in accordance with the probability of successful information transfer has been presented elsewhere (Siegel, Miehle,

and Federman, 1962). Since the sum of the link weights ($\Sigma \underline{w}$) may equal zero, this factor is represented as $1/1 + \Sigma \underline{w}$. Its greatest value is then one, and it approaches zero as $\Sigma \underline{w}$ increases indefinitely.

The directness factor, principle 2, rests upon the assumption that in an "ideal" system only one link will connect an indicator and a decision. Although redundancy (indicated by the presence of an symbol in the transfer diagram) reduces the probability of an operator error, a multiplicity of links to or from a source of information is, nevertheless, an undesirable feature. The factor which has a value of 1 under these conditions is

$$\frac{(n + m)_u^2}{2N\,(n + m)_t}$$

where $(n + m)_u$ is the sum of used indicators and decisions, $(n + m)_t$ is the total number of indicators and decisions, and N is the total number of information links. The lower limit of this factor is zero.

The minimum size system, possesses one indicator, one decision, and no logical operator functions. These aspects are covered in the data transfer factor, principles 5 and 6. They suggest the form, $2/Q + n_o$, which yields a value of unity when these conditions apply. Here, Q is the total number of display elements plus decisions and n_o is the number of gate, mixer, or box symbols on the transfer chart.

The match factor, principle 3, enters when there is more or less information supplied than is needed for the required act. The mismatch is this difference. The match factor uses the sum of the absolute information differences in logarithmic units and is given by

$$[\ \exp\ (-\tfrac{1}{4}\ \Sigma\ |M|\ )\ ]$$

For a perfect match $\Sigma\ |M| = O$, therefore exp (O) = 1 and there is no effect on the DEI.

Exponential Weighting of the Factors

The weights given the various factors were first determined so as to give maximum agreement with the judgment of the developers of the technique. At a later time, the DEI was enhanced and the weights determined on the basis of the agreement between DEI applications to a number of systems with the opinions of four experts who evaluated the same systems. Since

the DEI is composed of a set of factors, the weights are the exponents; and since the values resulting are usually very small, for interpretive ease, fractional exponents are used to raise the numerical value of the DEI closer to 1.

The formula of the DEI is:

$$\frac{(n+m)_u \; [\exp(-\frac{1}{4}\Sigma |M|)]}{(1+\Sigma_w)\sqrt{N\,(n+M)_t\,(Q+n_o)}}$$

This can be calculated by hand or on a digital computer from data obtained directly from the transfer chart and the task application.

Empirical Valdity of the DEI

The empirical validity of the DEI technique was developed by exponentially weighting the factors according to the criteria of maximum agreement between the mean opinion of a group of four engineers and psychologists,and the result of the DEI technique application on the relative effectiveness, from the information transfer point-of-view, of several design variations of six different equipment systems. Later, this preliminary weighting was cross-validated by applying the technique with the derived weights to variations of six other equipments and comparing the obtained DEI values with the composite ranking of the individual equipments of a different pool of four human factors experts. For various equipments, the obtained correlations between the DEI and the experts were:

Task	Correlation
Radio set AN/GRC-50 (radio communications)	.68
Radio set AN/GRC-66 (radio relay set monitoring)	.82
Radar set AN/MPQ-29 (operating adjustments)	.70
Radar set AN/MPQ-29 (target acquisition and radar tracking)	.70

Radar set AN/TPS-33 (starting, turning, and orienting equipment)	.80
Radar set AN/TPS-33 (detection of targets)	.60

Discriminating Power of the DEI

Discriminating power means the extent to which a metric will distinguish between differences in a variable. In the current application, the interest is in the extent to which the DEI distinguished among display types or presentation techniques. For the six validations described above, four or five equipment variations were included in the validational sample for each of the equipments considered. Some of the design modifications were quite minor; others were rather extensive. The range and median DEI values for each equipment were:

Task	Median ($x\ 10^{-2}$)	Range ($x\ 10^{-2}$)
Radio set AN/GRC-50	.0004	.0007
Radio set AN/GRC-66	.525	.153
Radar set AN/MPQ-29 (operating adjustments)	.067	.020
Radar set AN/MPQ-29 (target acquisition and radar tracking)	.311	.180
Radar set AN/TPS-33 (starting, turning, and orienting equipment)	.103	.185
Radar set AN/TPS-33 (detection of target)	.152	.156

These data strongly suggest that the technique possesses adequate sensitivity for distinguishing between variations in equipment design.

Purpose of Present Program

The prime purpose of the present research was to explore the use and validity of the DEI technique for large scale command and control display situations. While in the past the DEI technique was used to evaluate displays for transferring information to operators, and for the operators to act on this information (cf., Siegel, et al., 1962, 1964), in the present research the DEI technique was employed to evaluate displays for transferring information to operators and for the operators to use this information for decision-making purposes. By decision making, we mean the reception and conversion of information for use in formulating courses of action.

To this end the present study investigated, in two separate experiments, the decisioning ability of subjects when the information employed in making the decision is presented in four different display forms: (1) pictorial black-and-white, (2) pictorial-plus-color, (3) tabular black-and-white, and (4) tabular-plus-color. Employing as criterion scores, the scores of the subjects when each display mode was employed, the DEI values for these displays were compared with the criterion data. The resulting relationships were considered to be indicative of the validity of the DEI for predicting the criterion.

Previous studies have pointed to the value of color in visual information presentation (Smith, Farquhar, and Thomas, 1966; Silver, Landis, and Jones, 1965). The results of these investigators suggested that, in visual search tasks, items presented in various colors are more easily discernible than others. Hitt (1961) found color coding to be superior to such other coding methods as alpha-numeric classification, geometric shape coding, and configuration for several different tasks. However, most research into the effectiveness of color and other coding methods for use in large scale displays has involved aspects of data manipulation that are somewhat less complex than decision-making and dependent variables that do not involve decision correctness.

The present research investigated the effectiveness of color in large scale command and control displays and is an extension of previous studies in this area, in that the displays considered are to be used for transferring information needed for complex decision-making.

Smith (1963) found that error scores and search time increased with increasing display density. Silver, Landis, and Jones (1965) also found fact density to be a variable having critical effects upon decision-making ability. As such, it was decided to vary fact density (numerosity of enemy air threats) across three levels in the present work.

Aside from the effects of color and numerosity, one other hypothesis was formulated and investigated. Two different types of displays, pictorial and tabular, were involved. It was hypothesized that each is of value for facilitating different levels of information processing. The pictorial display presents a complete, holistic representation of the situation, although most pertinent factors are in a symbolic form. This display was hypothesized as being of greater value for complex situational judgments where the integration, interpolation or extrapolation of information from several sources is required. On the other hand, the tabular display, in which the information is presented in the form of continuous and discrete indicators involving quantitative values, was hypothesized as being superior for determining simple facts, such as system status, availability of units, and level.

CHAPTER II

INITIAL EXPERIMENT

As stated in Chapter I, the primary purpose of the present program was to validate the DEI technique for predicting the ability of operators to make the decisions involved in the command-control type of situation when large scale displays were employed. Secondary purposes involved comparisons of the power of two display types (pictorial and tabular) for various types of information processing and investigation of the advantages, if any, of color coding in this type of situation. In the first experiment, four display design presentation techniques were involved, e.g., pictorial black-and-white, pictorial-plus-color, tabular black-and-white, and tabular-plus-color. The task of the subjects was to extract information from, and make decisions (through the employment of a set of decision rules) on the basis of the information presented in the displays.

An ordered series of six stimulus situations was developed. Each pair of successive stimulus situations, in the graduated series, was considered, on the basis of the number of threats it contained, to be at a higher difficulty level. The number of threats contained in each stimulus was:

Stimulus Situation Number	Difficulty Level	Number of Threats
1	Easy	4
2	Easy	7
3	Intermediate	10
4	Intermediate	10
5	Difficult	12
6	Difficult	15

For each stimulus situation, four matched displays were developed: (1) pictorial (Figure 1), (2) pictorial-plus-color, (3) tabular (Figure 2), and (4) tabular-plus-color. Each display conveyed exactly the same information for a given stimulus situation, but in a different manner. Since six stimulus situations and four display types were included, a total of 24 stimuli was involved.

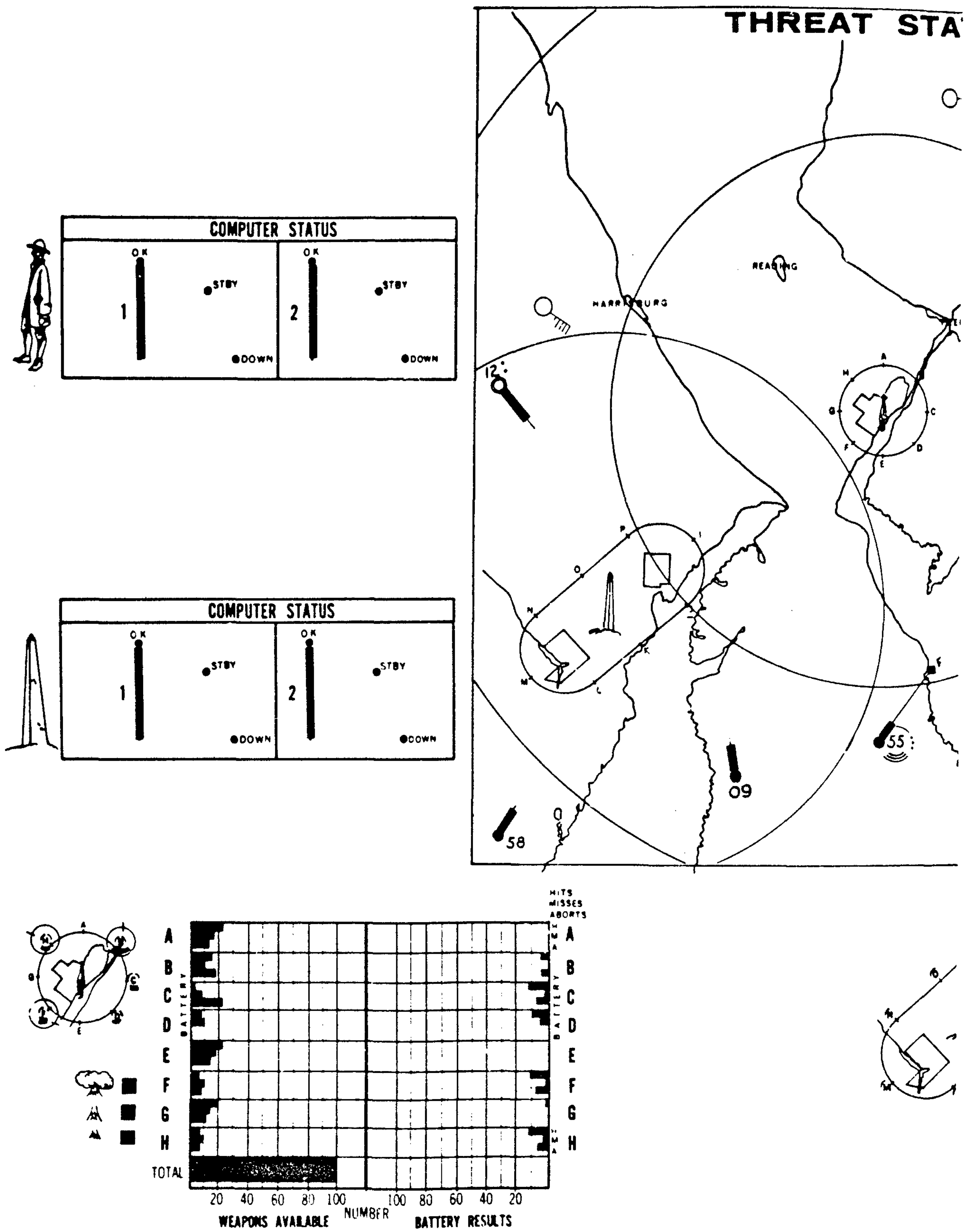
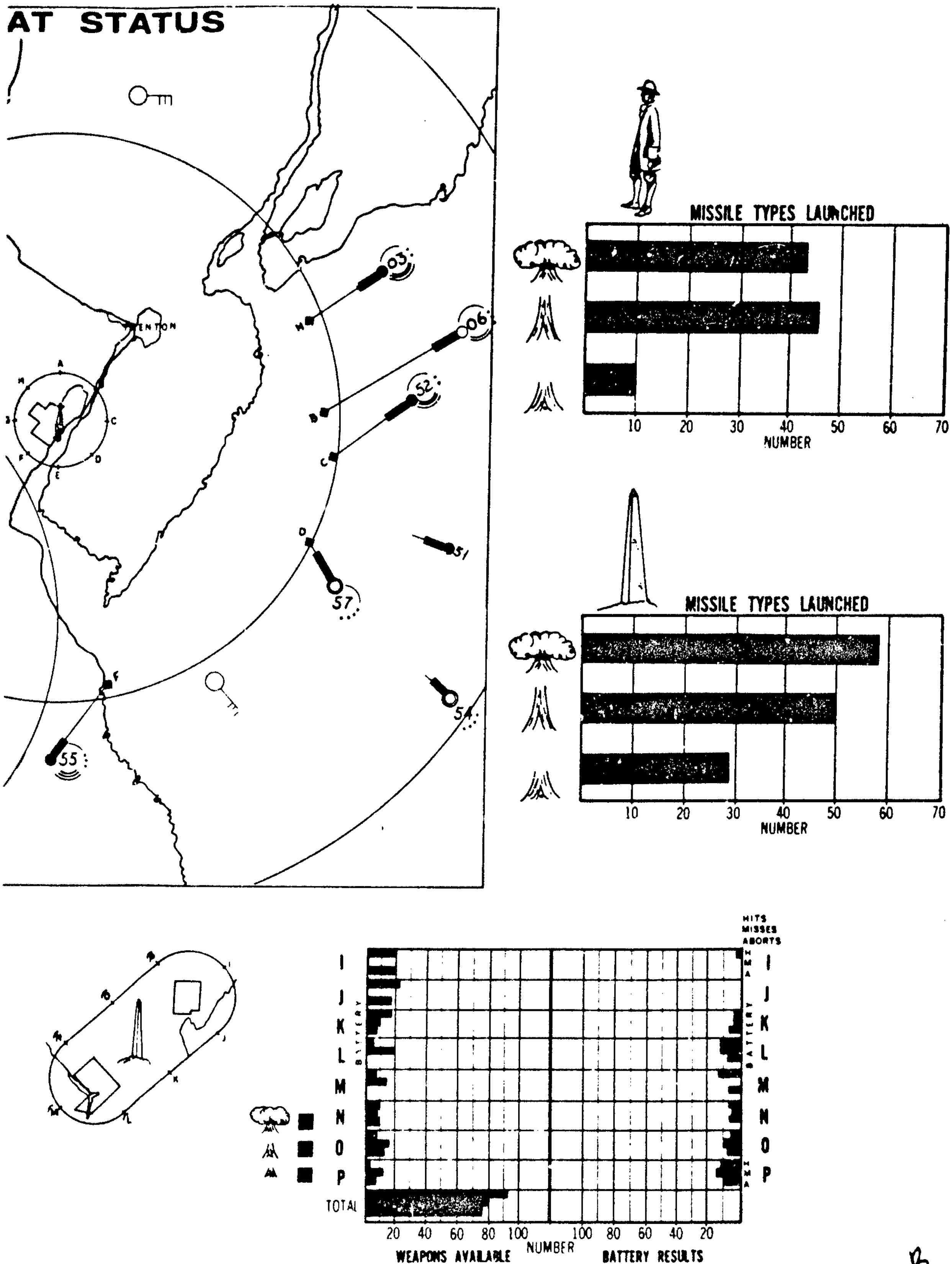


Figure 1 Example of pictoria

h



B

· of pictorial type display.

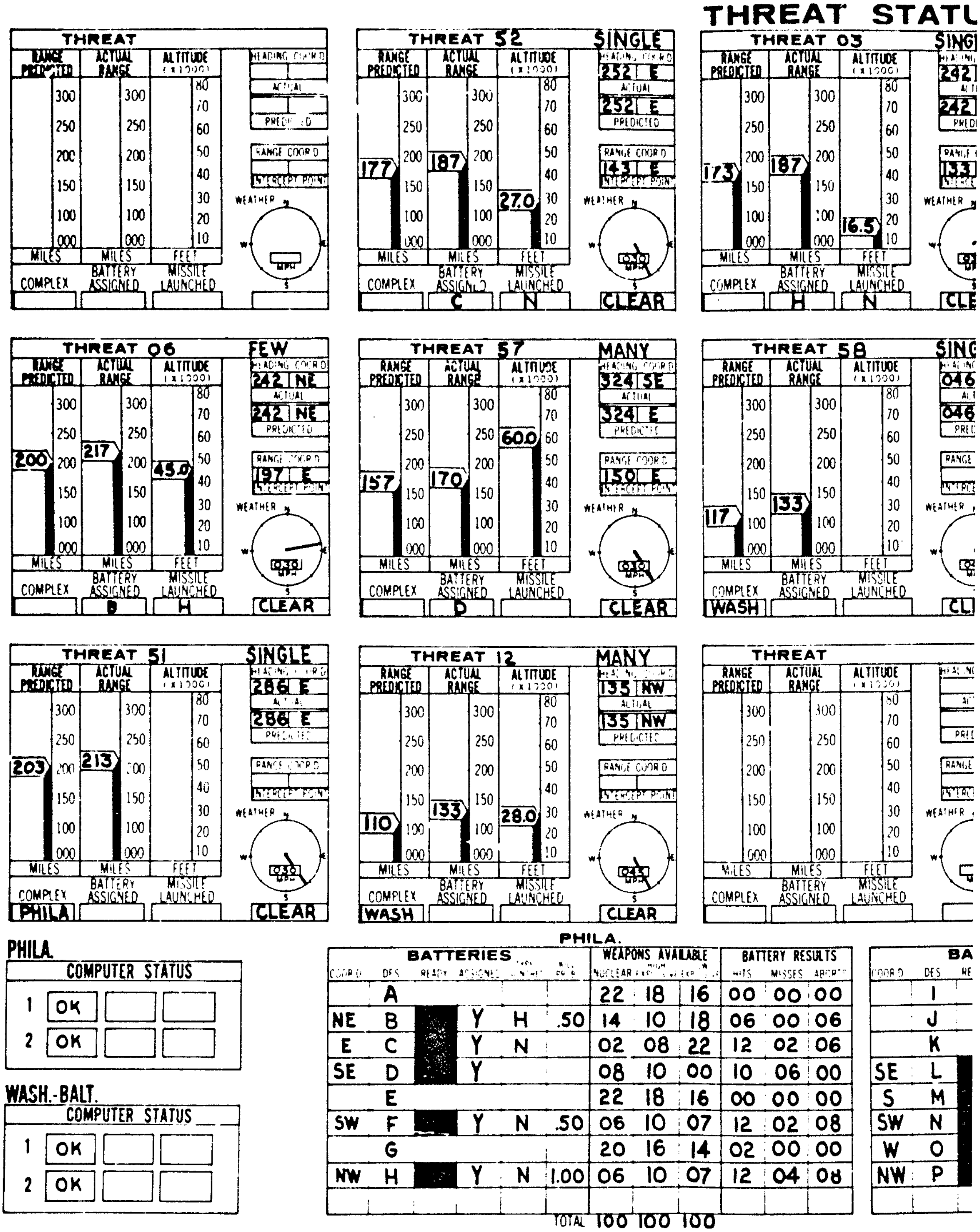
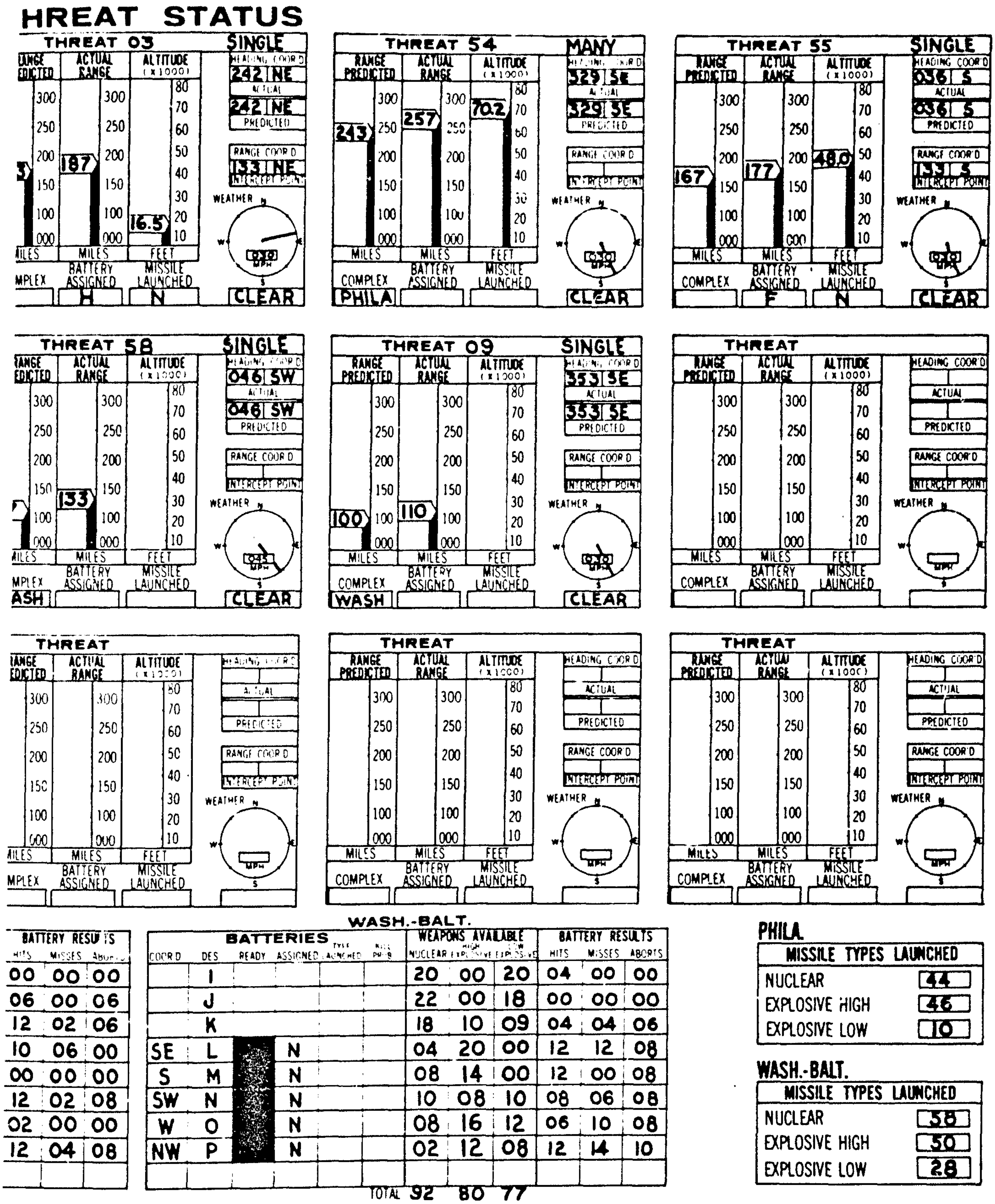


Figure 2 Example of tabular typ



Example of tabular type display.

B

Stimuli

The stimulus materials, were static visual displays, representative of large scale command and control situations. The situations involved the air defense of two major east coast complexes: (1) Philadelphia, and (2) a Washington-Baltimore composite.

Pictorial Display

The pictorial displays (Figure 1) presented both qualitative and quantitative information about the command and control situation. A map of the two major east coast complexes was presented in the sub-display labelled"Threat Status." In this sub-display, not only could the geography and relative positions of the defending batteries and attacking aircraft be readily determined, but weather information,as well as other threat relevant information,was presented.

Threat Status

Each threat was identified by a threat number. The threat number in Figure 3 is 05. Since 15 threats are the maximum number that could appear in any display (an arbitrary cut point), threat tag numbers could range from 01 to 15. If the threat number was prefixed with the numeral "5" (e.g., 54), the additional information that the threat contained a nuclear warhead was provided. The color displays presented this information redundantly. For these displays,if the threat was believed to be carrying a nucclear warhead, all threat information was also presented in purple.

If a battery was assigned to intercept a threat, a battery assignment arc appeared above the threat number. If no battery was assigned to the threat, the battery assignment arc was omitted from the display. Following the battery assignment arc was the indication of the altitude of the threat. One of four different altitude ranges could be indicated. One dot indicated an altitude of 0-14,999 feet; two dots, an altitude of 15,000-29,999 feet; three dots, the range of 30,000-49,999 feet; and four dots represented 50,000 feet and over.

If a battery assigned to a threat had launched a missile against it, one of three missile-launched indicators could appear. These corresponded to the three types of missiles that could be stored in the battery's stockpile. A single arc (as in Figure 3) represented the launching of a low explosive missile; two arcs indicated a high explosive missile launch; and three arcs indicated the launching of nuclear weapons. Color was also used when

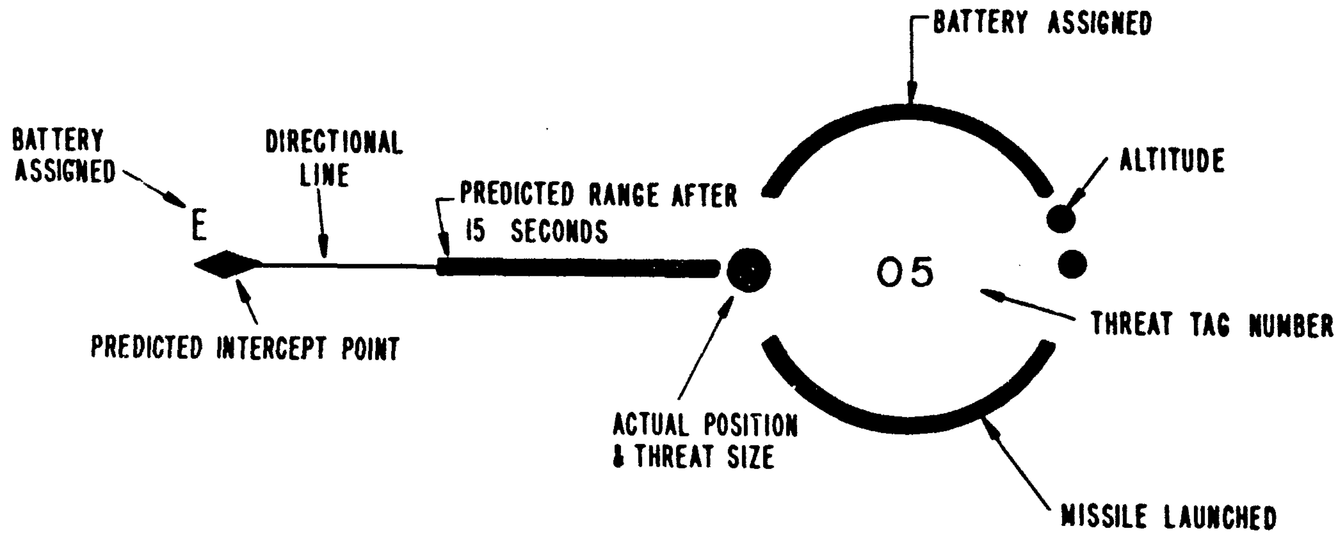


FIGURE 3. DETAILS OF THREAT APPEARANCE

presenting this information in the pictorial-color displays. Blue was used with single arcs, red with double arcs, and purple with triple arcs.

The threat's present position and sizewerecommunicated via circles which appeared immediately to the left of the threat number. The position of this circle indicated the present position of the threat and allowed extrapolative estimations of the distance of a threat from the center of a defense complex. The extrapolation of distance was facilitated through the use of standard marker circles, called the missile range circles. These represented a distance of 150 miles from the center of a complex. In the pictorial-plus-color displays, the missile range circle was red.

The number of targets or hostile aircraft contained in any threat could vary from one to 10 or more. If a threat was composed of a single target, a solid circle appeared (●). If the threat contained a few targets, that is from two to nine targets, an open circle (○) appeared. If there were many targets (more than nine) in the threat, an open circle with a band encircling it (◎) was presented. The band was colored red in the pictorial plus color displays.

A solid, heavy vector, emanatingfrom the threats "present position" circle locator, provided information regarding the threat's predicted position, after 15 seconds. Thus, the speed of the threat could be estimated, if necessary. In the color-coded version, if a threat was inside the missile range or would be inside within 15 seconds and still remain unassigned, the predicted range bar was colored brown.

Leading the predicted range vector was the directional line. This line indicated the relative direction in which the threat was heading and provided continuity to the predicted intercept point indicator, a diamond head. The predicted intercept point indicator, too, was colored brown if the threat was unassigned and inside the missile range,or was predicted to be inside of missile range within 15 seconds.

The final unit of information transferred through threat-related codes was the designation of the battery assigned to intercept a threat. A letter in front of an intercept point indicated the battery assigned to that threat. The actual locations of the batteries were communicated by alphabetic indicators around the defense complexes. Batteries A through H were the eight batteries surrounding the Philadelphia complex; batteries I through P were the eight batteries surrounding the Washington-Baltimore complex. A battery's position, around a complex, was never changed. In addition to geographic location, each complex was identifiable through a symbol, readily associated with its major city. A replica of William Penn appeared in the center of the Philadelphia complex and a replica of the Washington Monument appeared in the center of the Washington-Baltimore complex.

Weather over the area was also indicated. The weather symbols possessed no prescribed position; they could appear any place in the display. An open circle, ○ , indicated clear weather, Ⓡ indicated rain, Ⓢ indicated snow. Wind direction and velocity were indicated in the following manner: a line cutting the perimeter of the circle indicated the direction in which the wind was heading. Barbs at the end of this line indicated wind speed in miles per hour. Each full barb represented ten miles per hour; a half barb represented five miles per hour.

Battery Status

Directly below the threat status sub-display were battery status sub-displays, one for each complex. All the information specific to the batteries protecting the complexes were contained in these displays. Each battery's ready status, assignment status, type of missle launched, probability of killing the threat, weapons available, and a history of past performance were contained in the battery status sub display.

If a battery was ready to receive an assignment, an arc appeared above and to the left of the battery letter, as it was displayed in its position around the complex. In the color-coded version, the arc and the letter were green. If a battery was assigned to a threat, an arc appeared above and to the right of the battery letter.

Whenever a battery had launched a missile against a threat, the missile launch indicator appeared immediately below the battery letter. These were the same as those appearing in the threat status sub-displays. Again, color was used where indicated, blue for low explosive missiles, red for high explosive missiles, and purple for nuclear missiles.

Information was provided relating to the kill probability for particular threats, i. e., the chances a battery had in downing a particular threat. These codes were found surrounding the battery letter in its position around the complex. One of four different probability estimates could appear = 0.25, = 0.50, = 0.75, = 1.00.

Alongside the geographic complex portions of the battery status sub-displays, graphic exhibits were presented containing information relative to the available weapons (missiles) in the various batteries and the performance record of each battery. Bar graphs were used for these purposes. For the pictorial-plus-color displays, the bars were color coded to coincide with the three types of missiles stored by the batteries. The graphic displays of battery results presented a history of each battery's performance in terms of the number of hits, misses, and aborts during the present battle.

Computer Status

Two computers were associated with each major complex. Three different readiness states were delineated for each computer: "ok," "standby," and "down." Indicator bars pointed to the legend designating the current state of the computer. In the color displays a green bar meant "ok," a red bar stood for "down," and a black bar was used for "standby." The symbols used to identify Philadelphia and Washington-Baltimore were the same: William Penn and the Washington Monument.

Missile Types Launched

The final sub-displays in the pictorial presentations referred to the missile types launched by the batteries in each complex. These were graphic presentations of the number of missiles of each of the three types, that had been launched. For the displays involving color coding, the same colors were used for each missile type as had been used in the previously discussed sub-displays.

Tabular Displays

The counterpart of pictorial display, the tabular display (Figure 2), directly presented all the information contained in the pictorial displays. Here, digital-counter, alpha-numeric, and lensed-legend billboard and pointer type visual displays were involved. Precisely the same information was presented on the tabular displays as on the pictorial displays. Hence, for any given situation, threat status, battery status, and missile information, etc., were identical across the two display types. The tabular display contained no figural or pictorial presentations, but relied exclusively on symbolic presentation of information.

Threat Status

All relevant information pertaining to individual threats was contained in individual threat status blocks (Figure 2). Here, the threats were identified by threat number, ranging from 01 to 15. A threat tagged with a number starting with the numeral "5" contained a nuclear warhead. Color was used in the tabular-plus-color displays to indicate a threat containing a nuclear warhead. Thus, a nuclear threat was indicated by both a tag, which started with the number "5," as well as the presentation of this information in blue (as was the case for the pictorial-plus-color displays). The size of the threat followed the threat number on the top line of the threat status

block. "Single," "few," or "many" were used. In the color displays, when "many" was used, the word "many" appeared in red.

Altitude, actual range, and predicted range were presented through moving pointer and three or four drum counter displays. The pointers indicated qualitative values by pointing to a vertical index and were constructed so that there was a "window" at the tip of the pointer in which actual quantitative values appeared in digital form. It was also possible to read these indicators qualitatively on the basis of the height of the vertical "thermometer" contained in each, or on the basis of the level of the counter. For the tabular-plus-color displays, if a threat was unassigned and inside the missile range or was going to be inside within the next 15 seconds, the predicted range information was presented in brown (as in the pictorial-plus-color displays).

Below these indicators, battery assignment, missile launch, and defense complex information was provided. If a battery had not yet been assigned to a threat, the complex from which a battery was to be selected appeared in the window provided under "Complex." This would be either "Phila" or "Wash" and was based on the proximity of the threat to each complex. An assignment was made to a battery in the complex closest to the threat. If a battery was assigned to the threat, its letter appeared in the "Battery Assigned" box and the "Complex" box remained empty. Since the letters A through H were designators for Philadelphia, and I through P for Washington-Baltimore, further identification of the complex was not provided. When a battery launched a missile against a threat, the type of missile used appeared in the "Missile Launched" box; "L" for low explosive, "H" for high explosive, and "N" for nuclear. In the color displays the "L" was blue, the "H" was red, and the "N" was purple.

The actual heading and the coordinates of the threat were presented in a digital manner. The actual heading was indicated by the polar heading of the threat in degrees, as measured from its actual or present position. The actual coordinates indicated the present position of the threat in terms of compass bearings, i.e., N, NE, E, SE, S, SW, W, and NW. Thus, sufficient information was provided to locate a specific threat. The same information was provided for the predicted heading and coordinates. These were heading and coordinate predictions for 15 seconds hence.

The intercept point was located in terms of range and coordinates. Range was indicated in miles from the center of a complex and the coordinates were presented in compass bearings.

The weather indicators were specific to each threat. Wind information was given by a counter-pointer combination. Wind direction was

indicated by the pointer; wind velocity was presented, in miles per hour, by the digital counter. The weather conditions appeared in a lensed-legended indicator immediately below the wind information. One of three weather conditions could appear: rain, snow, or clear.

Battery Status

The first column in the battery status billboard, labelled "Coor'd," provided the compass bearings of the batteries around the complexes (e.g., N, NE, E, SE, S, SW, W, and NW). The battery designators appeared in the second column. In the tabular-plus-color displays, when a battery was ready to receive an assignment, its letter in the second column appeared in green. In addition, all ready batteries were indicated by a solid box in the third column. This indication was green for the tabular-plus-color displays. Those batteries already assigned were designated with a "Y" (yes) in the fourth column; unassigned batteries had a "N" (no) in the assigned column.

Missiles launched by batteries were indicated in the next column. "L" was used for low explosive, "H" for high explosive, and "N" for nuclear. The tabular-plus-color displays presented this information in blue, red, and purple, respectively. The kill probability was presented in the following column. The probability appeared alongside the battery assigned to the threat for which the kill probability had been calculated.

Digital counter displays were used to provide the weapons available and battery results information. Color coding was used in displaying the weapons available in the color displays. These were again blue, red, and purple for low explosive, high explosive, and nuclear weapons. Battery results received no color coding.

Computer Status

Computer status was provided through one of three simulated lensed-legend indicators. These could be read "ok," "standby," or "down." Green was used for "ok," black was used for "standby," and red was used for "down" in the color displays.

Missile Types Launched

The total number of each type of missile launched by a complex was provided in the missile types launched sub-display. Blue, red, and purple were used to identify the appropriate missile type in the tabular-plus-color displays.

Apparatus

The displays of the command and control situations were prepared in lantern slide form. The use of lantern slides allowed for projected images of adequate definition and a total picture size of four feet by five and one-quarter feet. Thus, the subjects were able to read the displays, with relative ease, at viewing distances of from six to ten feet. The colors, in both the pictorial and tabular displays, were adequately bright and saturated against their white screen background.

The subjects were seated in a quiet, semi-darkened room and provided with lap boards to support their writing materials. The arrangement of seats in front of the projection screen was constant for all groups of subjects. To minimize the displacement and distortion of the projected images, the seats were arranged so that none was at an acute angle to the screen.

The Decisions

The visual displays provided the information for a series of decisions, which the subjects were required to make on the basis of the information displayed. The adequacy of these decisions served as an indication of the ability of the display to transfer information. Two "decision levels" were used. The more difficult level, referred to as "decision-making, " was complex enough to require the integration of several different aspects of the information provided. The other level, "information availability, " was less complex and merely required the subjects to read or extract information from the displays. Thirty decision questions were answered by each subject for each display; twenty were of the information-availability type and ten were of the more complex decision-making type. Examples of questions classified under decision level I, information availability, were: How many batteries are unassigned?, How many threats are above 29, 999 feet?, How many threats contain nuclear warheads? Examples of decision-making, decision-level II, questions are: Which weapon should battery A launch against threat 52?, To which battery should threat 08 most probably be assigned?, If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex? A complete list of the questions, for each stimulus, appears in Appendix A to this report.

Decision Rules

The logic for making the decisions was provided to the subjects in the form of a set of decision rules or ground rules. These ground rules are presented as Appendix C to this report. The ground rules included

instructions for making decisions on battery assignment, weapon selection, wind and weather considerations, target selection, etc. For example, in determining if a nuclear missile should be launched against a threat, a subject was required to consider and see that the following conditions were satisfied: (1) the wind was not in the direction of the complex, (2) the threat had a few targets (2 to 9) or many targets (10 or more), (3) the threat contained a nuclear warhead, (4) the threat was above 14, 999 feet, and (5) the predicted intercept point was or would be more than 50 miles from the center of a complex. As a second example, in determining which battery to assign to a particular threat, the decision rules stated that a threat should be assigned to the nearest unassigned battery with at least five of the appropriate weapon type available. If two batteries were equidistant from the threat, and each had at least five of the appropriate weapons available, the battery was to be selected that had the highest "batting average." Batting average was determined by using the following formula:

$$\text{Batting average} = \frac{\text{Hits (this battle)}}{\text{Misses + Aborts (this battle)}}$$

The training of the subjects in the use and application of the ground rules is presented in a later section of the present chapter.

Subjects

Twenty male subjects were used in the experiment. They were all undergraduates at two local colleges, Eastern Baptist and La Salle. The subjects were assigned randomly to one of four groups. However, no more than three subjects from either college were assigned to any one group, thus controlling for any college specific bias which might have been involved. A group was composed of five subjects. Each group was identified with a particular display presentation technique (pictorial, pictorial-plus-color, tabular, and tabular-plus-color) and all the stimuli presented to the group were of its respective type. All subjects had normal color vision.

The subjects were paid $1.50 per hour for their participation.

Subject Training

At the first of three sessions, conducted separately with each of the four groups, the subjects were given a brief semi-structured introductory lecture. In this lecture, the purpose of the study and the experimental procedures were explained. The subjects were informed that Applied

Psychological Services was under contract with the Air Force to perform research into the effectiveness of different types of visual displays for transferring information and the subsequent use of this information for making decisions. Since air defense-type programs were selected as vehicles for studying the problems at hand, the subjects were to think of themselves as assignment officers.

In addition, the following points were covered in the initial lecture. The static displays were to be thought of as photographs,or stills,of dynamic and constantly changing situations in a air defense circumstance. As assignment officers, the subjects had control over two complexes--Philadelphia and Washington-Baltimore. The training program at this first session involved learning to read the displays and training in the use of the ground rules. The pay was $1.50 per hour and a bonus would be given to those who achieved a criterion score.

The task of the subjects was amplified and they were told that there would be six independent command and control problem situations. They would answer questions on each command and control problem. Before the actual training session began, the subjects were further informed that the first session was primarily for training; a second session for both retraining (during which a complete review of all the material covered in session I would occur) and administration of one-half of the experimental problems was involved; and in the third session the other half of the experimental problems would be administered.

Since learning ability was not an experimental variable, it was considered necessary to allow for as much training as was necessary to bring the subjects to a satisfactory initial level of proficiency.

A folder containing display reading instruction sheets and the decision ground rules was then distributed. The display reading sheets presented all the display symbology (and color coding for the "color" groups) to be learned.

Examples of such symbolism found in the pictorial displays were the altitude readings (i. e., • = 0-14, 999 feet, : = 15, 000-29, 999 feet), the missle launched arcs (◡ = low explosive weapon, ◡ = nuclear weapon), and threat size (● = single target, ○ = few targets). Examples of codes in the tabular displays were missiles launched (L = low explosive, N = nuclear), actual coordinates (N = north, S = south), and battery assignment status (Y = yes, N = no).

Then, an especially constructed training slide was projected on a screen and the display coding and ground rules were covered in detail.

Questions were encouraged and answered. The subjects were then told to take the ground rules and display-reading instruction sheets with them and to study these sheets before the next meeting. They were advised that they would be tested on the material involved and that they would be paid for two hours of study time.

The first part of the second session repeated the training given in session I, using the same training slide. Then a test, appearing in Appendix D to this report, was administered. Only a few errors were made on the test. The frequency distribution of test scores was:

Scores	f
96-100%	9
91-95	7
86-90	2
81-85	2
	20

The test was scored immediately and errors were corrected with the group. At this point the subjects within a group were considered ready for participation in the first data collection session.

Display Administration

Immediately following the second training session, the first three of the six research stimulus situations were administered. The second three display situations were administered in a third session a day or two later. Each session lasted two-three hours, including five-minute breaks after each hour.

The order of presentation of the six stimulus situations was systematically counterbalanced so as to distribute any practice or fatigue effects systematically over the data. Thus, each group received its problems in the same sequence which was based on difficulty level--"easy," "intermediate," "difficult," "difficult," "intermediate," "easy."

The procedure for exposing the stimuli and eliciting answers to the decision questions was based on the results of a pilot study (described below). After distributing the question booklets, the group was allowed 15 seconds to read the first question to be answered. The first slide was then projected for 30 seconds during which time the subjects were expected to: extract the information required for reaching the necessary decision, reach the decision, and enter the decision on an answer sheet. Thus, for any one

question, effectively, 45 seconds were allowed. Following the answering of the first question, the screen was blanked and the subjects read the next question to be answered. Then the slide was re-exposed for 30 seconds. This procedure was repeated until the 30 decisions had been reached for a slide. After making 30 decisions for a slide, the answer sheets were collected, new answer sheets distributed, and the procedure was repeated for the next stimulus situa'ion.

Each subject answered 30 questions for each slide,and six slides were involved for each display type. Thus,180 decisions were obtained per subject.

Pilot Study

After the command and control situations were constructed, but prior to their drafting and transposition to lantern slide form, a pilot study was performed. Two male college students were used as subjects in the pilot study. The primary purpose of the pilot study was to verify the feasibility of the research administrative procedures, the decision questions, and the instructions.

The subjects were presented with several of the command and control situations. In each case the subjects were required to answer the thirty decision questions. One subject was shown only the pictorial-plus-color displays; the other only the tabular-plus-color displays. The pilot study served to verify, and,in some cases modify, the study procedures to be used.

Results and Discussion

Each subject's decision scores (number of current responses) were calculated. The decision scores were based on information availability (decision level I), decision-making (decision level II), and total (the sum of both decision levels) responses. Separate analyses were performed on these three data sets.

Variance Analyses

Initially, the variables of concern were the effect of display type (pictorial, pictorial-plus-color, tabular, and tabular-plus-color), and difficulty level among the six command and control situations. Consequently, these variables were subjected to a variance analysis. Tables 1, 2, and 3 present the summaries of these analyses of variance.

Table 1

Summary of Analysis of Variance for Decision Level I (Information Availability)

Source of Variation	SS	df	MS	F
Problems (P)	108.94	5	21.79	7.50*
Display Types (DT)	35.36	3	11.79	3.82**
P x DT	41.89	15	2.79	
Error	296.80	96	3.09	
TOTAL	482.99	119		

*Significant at or below the .01 level of confidence
**Significant at or below the .05 level of confidence

Table 2

Summary of Analysis of Variance for Decision Level II (Decision Making)

Source of Variation	SS	df	MS	F
Problems (P)	113.74	5	22.75	13.23*
Display Types (DT)	56.96	3	18.99	11.04*
P x DT	51.69	15	3.45	2.01**
Error	165.60	96	1.72	
TOTAL	387.99	119		

*Significant at or below the .01 level of confidence
**Significant at or below the .05 level of confidence

Table 3

Summary of Analysis of Variance for Both Decision Levels

Source of Variation	SS	df	MS	F
Problems (P)	314.37	5	62.87	10.17*
Display Types (DT)	72.30	3	24.10	3.90**
P x DT	73.70	15	4.91	
Error	593.60	96	6.18	
TOTAL	1053.97	119		

*Significant at or below the .01 level of confidence
**Significant at or below the .05 level of confidence

The analyses of variance resulted in between problem F ratios, which were significant at, or below the .01 level of confidence for each decision level analyzed individually, and for the total across both levels.

Difficulty Level

The significant differences among problems support the finding of Silver, Landis, and Jones (1965) and indicate that poorer decisions result as threat numerosity (fact density) increases.

Tukey's test for significant gaps among individual means was applied to each of the data sets. For decision level I, the results indicated two significantly different groups ($p < .05$): the "easy" and "intermediate" problem scores, which were not significantly different from each other, composed the higher mean information availability score group, and the lower mean information availability score group was composed of the "difficult" problems. For decision level II, there were three significant groups: the "easy" problems (highest mean decision score group) were significantly different from the "intermediate" problems ($p < .01$), and the "difficult" problems ($p < .01$), and the "intermediate" problems were significantly different from the "difficult" problems [lowest mean decision score group ($p < .05$)]. For the total of both decision levels, again there were two statistically significant groups; the "easy" and "intermediate" problems although differing significantly from the "difficult" problems ($p < .01$) did not differ significantly from each other.

Figure 4, presents the effect of increasing difficulty level on decision score. Threat numerosity seemed to have had a greater effect on decision level II than on decision level I. Lesser effects on decision score were observed between the "easy" and "intermediate" levels of difficulty than between the "intermediate" and "difficult" levels.

Display Type

The analyses of variance resulted in significant between-display type F ratios at either the .05 or .01 levels of confidence for both levels of decision making and for the total across both levels. The Tukey test for significant gaps among the treatment means indicated two significantly different groups ($p < .01$) for decision level I. The higher mean decision score group consisted of both tabular displays and the pictorial-plus-color display. The lower group consisted of the pictorial black-and-white display type. In decision level II, two significantly different groups ($p < .01$) were also identified. Pictorial-plus-color displays were significantly different from the

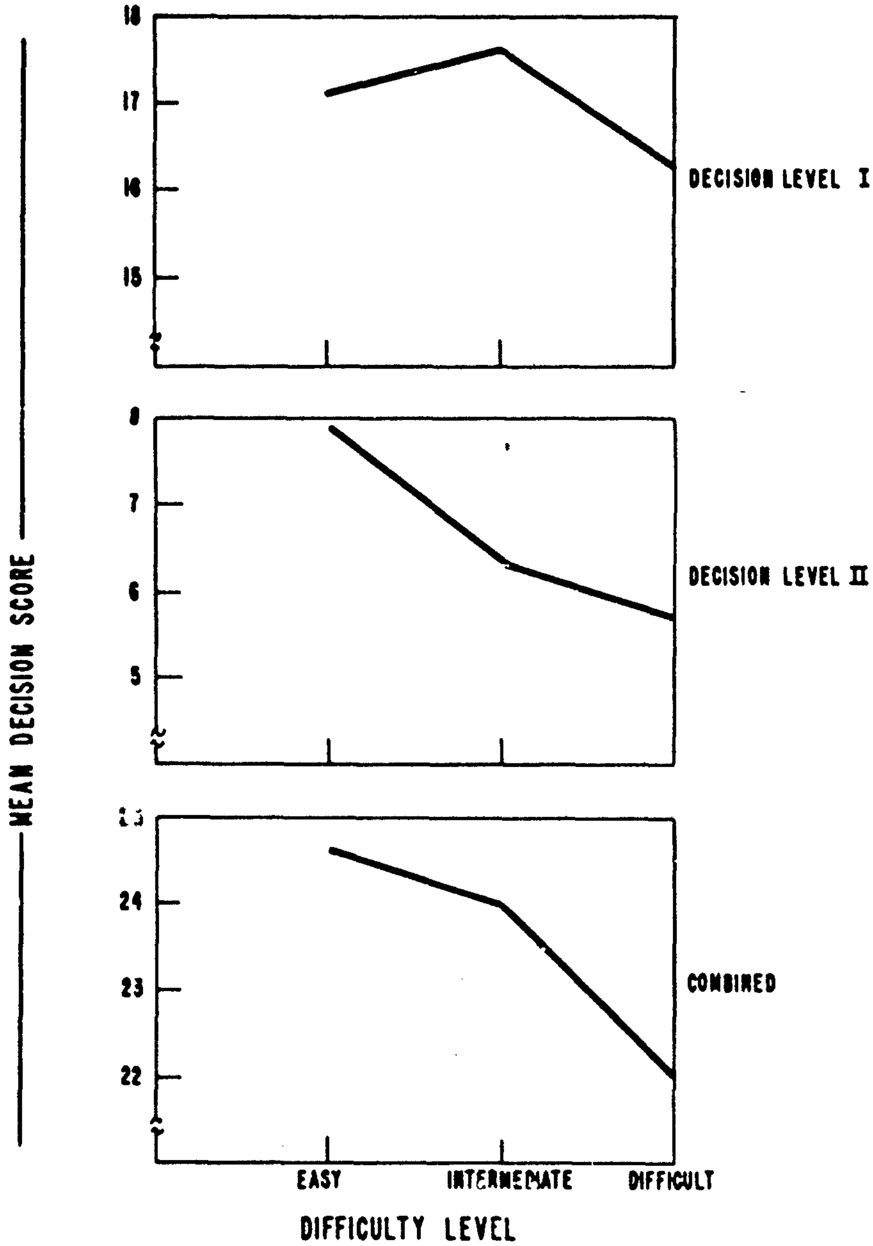


FIGURE 4. DECISION SCORE AS A FUNCTION OF DIFFICULTY LEVEL.

other three display types. When the total for both decision levels was considered, the pictorial-plus-color display, with the highest mean decision score, was significantly different from the tabular-plus-color and the pictorial black-and-white displays. Figure 5 presents the mean decision scores for the two decision levels and the mean total score, for each display type.

The scores on the pictorial and the tabular displays, at the various difficulty levels, are presented in Figure 6. These figures suggest that for decision level I, information availability, the tabular displays were superior to the pictorial displays at all levels. This finding is believed to reflect the nature of the information availability questions which involved direct read-outs from the displays without comparisons, extrapolations, interpolations, and the like. However, where the decisions were more complex and involved,the integration of several components of the display, rather than just reading out information, the pictorial display seemed to have an edge in the direction of improving decision-making. From the graph of Figure 6,which shows the relationship across both decision levels, the pictorial display seems to be generally superior. Thus, the gross statement that pictorial displays generally facilitate complex decision-making seems supported.

Color Coding

The effect of color on each of the display types is indicated in Figure 5,and the effect of color on each difficulty level within each decision level is shown in Figure 7. Figure 5 suggests that color had a positive effect when the pictorial type display was employed. Color did not seem to influence decision scores positively when the tabular displays were involved. Figure 7 suggests that color helped decision-making more than information extraction. An increase of 19 per cent was attained in the decision-making score when color was used in the pictorial display. There was a five percent increase in the score when information extraction was involved. The effect of color seems to hold quite generally, but it is noted that it did not seem to hold for the easy problems of decision level I. It is quite possible that information extraction, at the simple level and when adequate time is allowed, is easy enough as to be unaffected by color coding.

Redundancy

The effect of redundancy of information on the information availability items (decision level I) was examined further. Figure 8 indicates that, in general, as redundancy increased from zero to three (the maximum

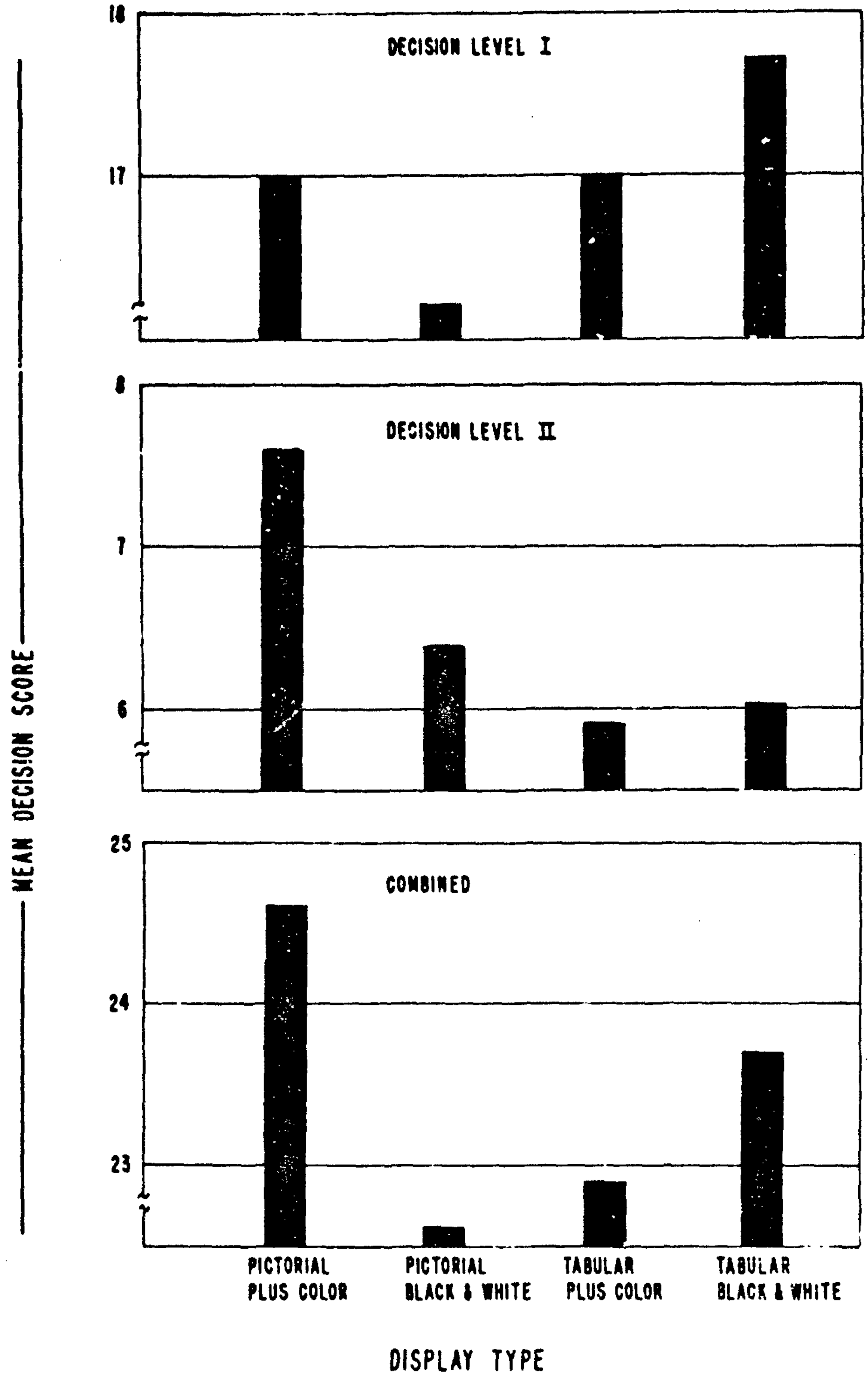


FIGURE 5. DECISION SCORE AS A FUNCTION OF DISPLAY TYPE.

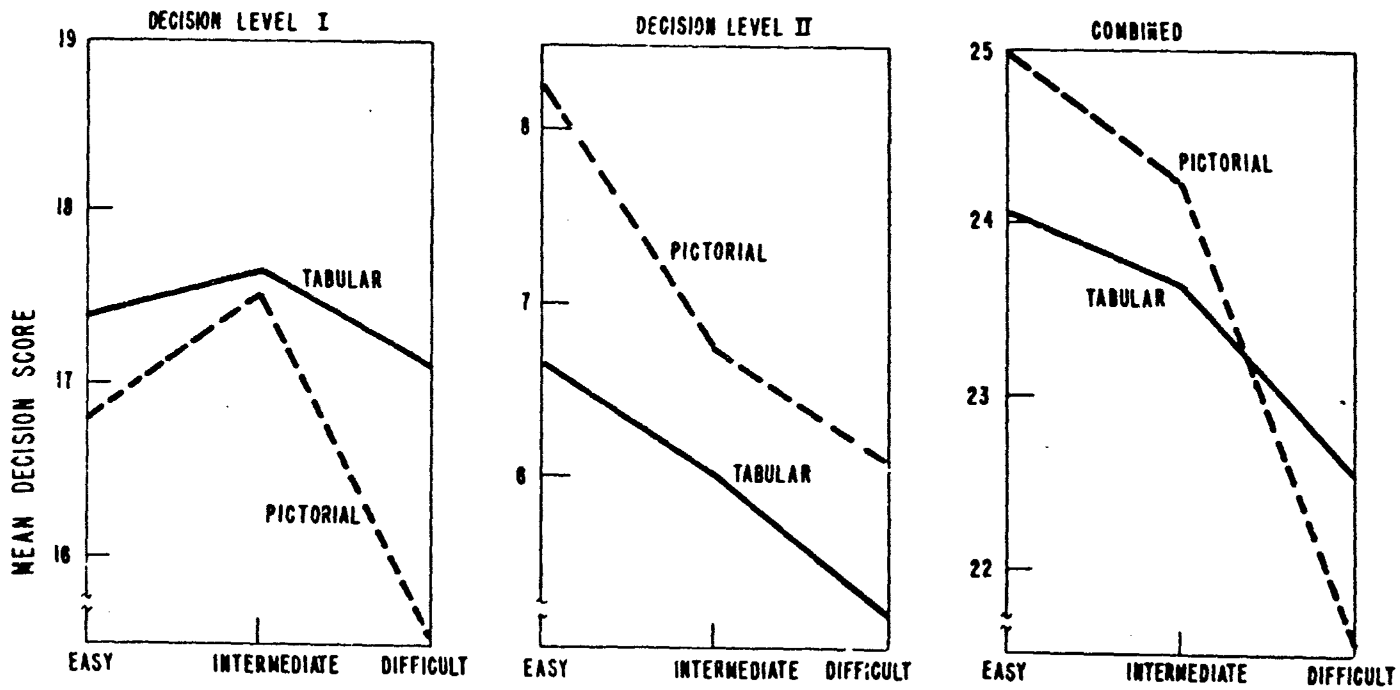


FIGURE 6. DECISION SCORE FOR PICTORIAL AND TABULAR DISPLAYS AS A FUNCTION OF DIFFICULTY LEVEL.

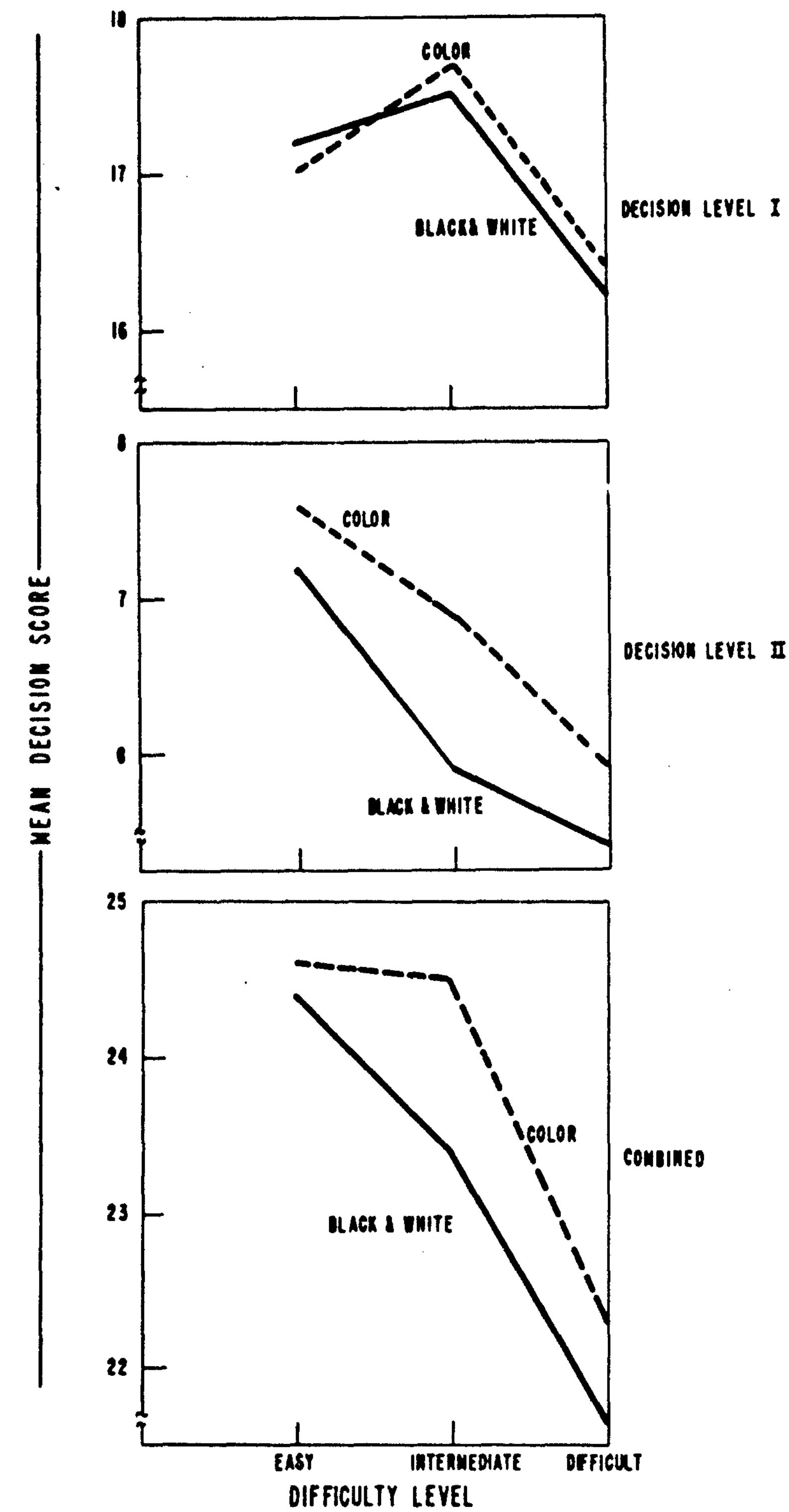


FIGURE 7. DECISION SCORES FOR COLOR AND BLACK-AND-WHITE DISPLAYS.

amount of redundant information), there was an increase in the number of correct responses. Redundancy of information was determined by the number of symbols and sources providing the same information. For example, in the pictorial display, a ready battery was indicated by a ready arc; if the display was in color, the ready arc and the battery letter were presented in green. Thus, in the pictorial black-and-white display type, the decision pertaining to the number of ready batteries was considered as having zero redundancy. However, in the pictorial color display, redundancy of ready status information was considered as having a value of two. In general, the anticipated positive effect of redundancy on information extraction is indicated by Figure 8.

Application of the DEI Technique

The Display Evaluative Index technique (DEI) was applied to the six command and control problems, and to each of the four display types through which the information was conveyed. The DEI results in a hierarchical ordering of displays. The resulting values do not relate displays on an absolute scale, but rather on a relative scale, or continuum, purporting to represent the information transfer effectiveness for the purpose of decision-making. Table 4 presents the indexes resulting from application of the DEI technique to the display types. An example of the computations of a DEI is presented in Appendix F. The resulting DEI values are presented in rank order, in both columns and rows, from high to low. The fact that the DEI resulted in a higher value for the less difficult problems reflects the effect of numerosity on information transfer effectiveness. This tendency is supported by the data presented earlier.

Table 4

DEI Values for Problems and Display Types

Problem	Pictorial-plus-Color	Pictorial Black-and-White	Tabular-plus-Color	Tabular Black-and-White
1	.276*	.208	.202	.147
2	.267	.195	.145	.107
3	.200	.144	.102	.078
4	.151	.117	.099	.076
5	.119	.093	.091	.071
6	.106	.082	.040	.031

*For the calculation of this DEI value, see Appendix F. All other DEI values were similarly calculated.

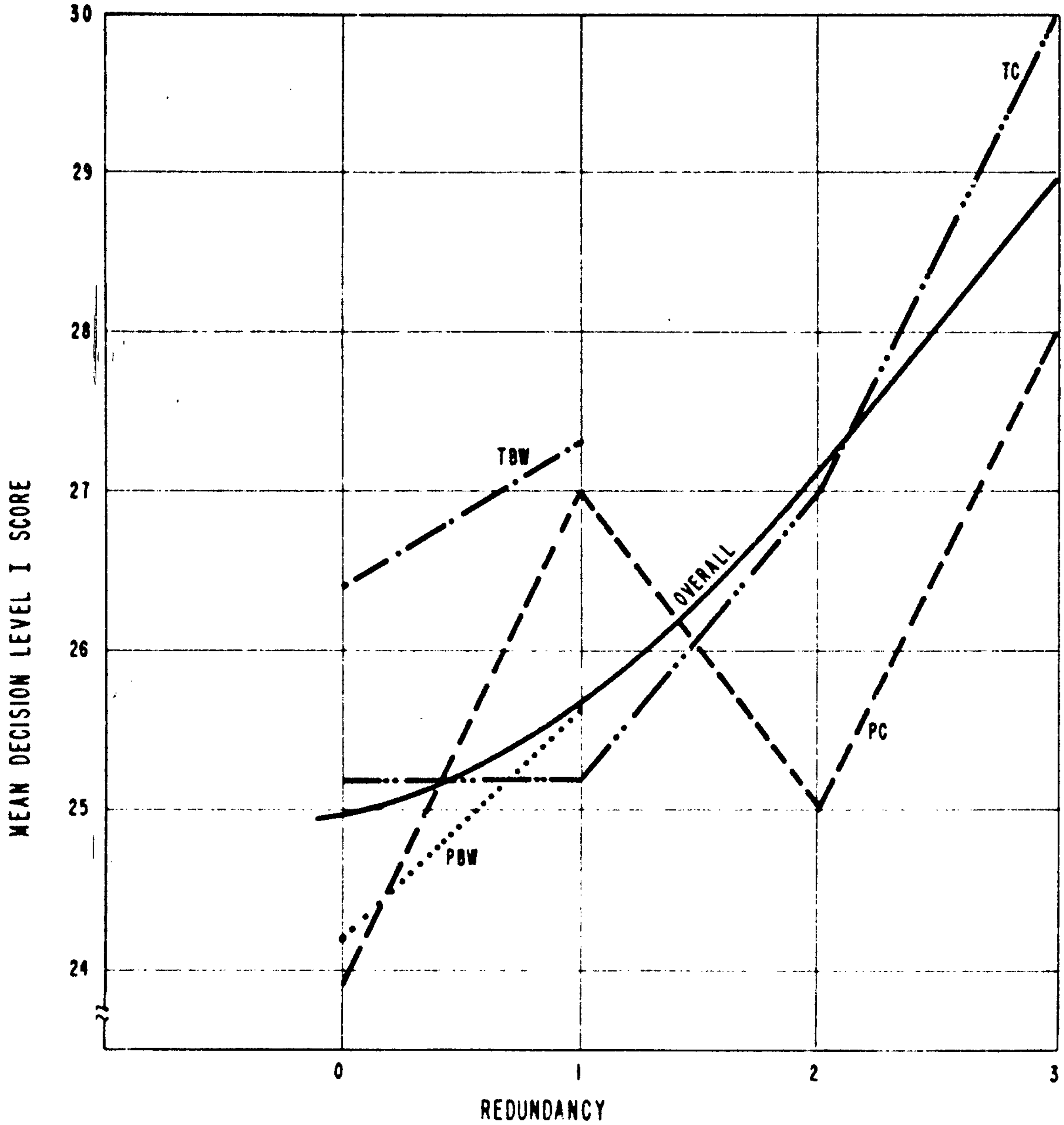


FIGURE 8. DECISION LEVEL I SCORE AS A FUNCTION OF REDUNDANCY OF INFORMATION.

In addition to ranking the displays in an order of merit relative to problem difficulty level, the DEI also ranked the display types within each problem. Thus, pictorial-plus-color, pictorial black-and-white, tabular-plus-color, and tabular black-and-white was the relative rank order obtained from the application of the DEI.

Color, as opposed to black and white, resulted in higher DEI values, because of its effect as an enabling factor. This tendency was also seen in the objective decision scores reported earlier. That is, whenever color provided relevant, rather than redundant, information, it enabled the decision-making process and also reduced the number of display elements needed to reach a specific decision.

The pictorial displays showed greater DEI values than the tabular displays. This tendency was also seen in the more objective decision data reported earlier. The factors in the DEI causing the pictorial displays to rank above the tabular displays were the Q factor and the mismatch factor. The DEI penalizes displays which, although providing the same information needed to make the same decisions, use a larger number of display elements to do it. Similarly, the DEI will penalize displays which provide more information than is needed to reach certain types of decisions, as was the case in decision level I. In this experiment, the information presented via the tabular displays used more display elements (more noise) than were needed for making specific decisions.

Correlational Analyses

For purposes of relating the obtained DEI values and the empirical results of the experiment, as measured by the decision scores, a series of correlations was performed. Correlational analyses were performed on the data representing decision level I by display type, decision level II by display type, the total for both decision levels by display type, decision level I across the four display types, decision level II across display types, and the total for both decision levels across display types.

Triserial correlations were used to obtain these measures of relationship (Jaspen, 1946). The triserial correlation is a useful statistic when one variable is continuously distributed (decision score) and the other is segmented into three categories (difficulty level). Criterion ratings of "easy," "intermediate," and "difficult" problems, which were based on the DEI calculations of the command and control displays, were correlated against the appropriate decision score. The obtained triserial correlations are presented in Tables 5, 6, 7, and 8.

Table 5

Triserial Correlation Coefficients Between Criterion Ratings and Decision Scores for Decision Level I

Display Type	Correlation
Pictorial plus color	.27
Pictorial black and white	.17
Tabular plus color	-.10
Tabular black and white	.22

Table 6

Triserial Correlation Coefficients Between Criterion Ratings and Decision Scores for Decision Level II

Display Type	Correlation
Pictorial-plus-color	.66
Pictorial black and white	.68
Tabular plus color	.42
Tabular black and white	.32

Table 7

Triserial Correlation Coefficients Between Criterion Ratings and Decision Scores for the Total of Both Decision Levels

Display Type	Correlation
Pictorial plus color	.28
Pictorial black and white	.29
Tabular plus color	.08
Tabular black and white	.17

Table 8

Triserial Correlation Coefficients Between Criterion Ratings and Decision Scores Across Display Types

Decision Level	Correlation
Decision level I	.13
Decision level II	.45
Total	.20

It becomes apparent that the magnitude of the correlation coefficients, although not exceedingly high, support a contention favoring the predictive validity of the DEI technique as an objective and impartial calculational device for quantitatively determining the ability of displays to transfer information to an operator and for the operator to use this information for decision-making. The correlation coefficients reveal a relatively close relationship between the DEI and decision level II scores, as indicated in Tables 6 and 8. Also from Tables 5 through 7, it's apparent that the DEI correlated more closely with the decision scores resulting from the pictorial displays rather than the tabular. The lowered correlations between the DEI values and the information availability scores are believed to be an artifact of the content of the DEI. The DEI is based on considerations which are more involved in decision-making and not on information extraction considerations.

Probability or Information Transfer Analysis

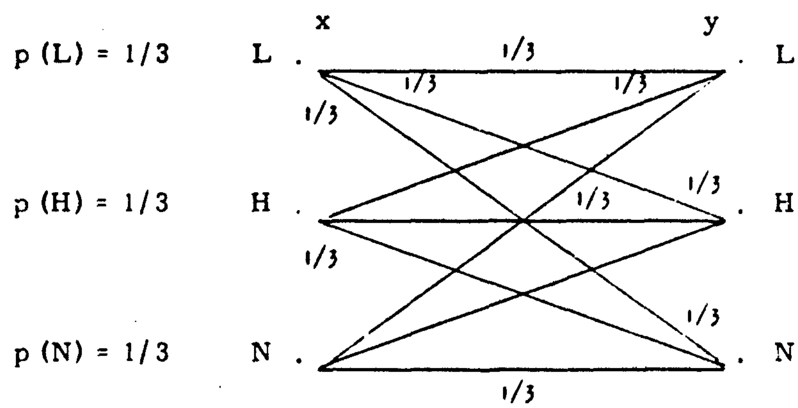
A display may be viewed as a device for conveying information from a source to an operator. The quality of the display, or its effectiveness, can be determined from its capacity to convey the information correctly. The concepts of information theory, which are derived essentially from Bayes' theorem, but use it in a logarithmic form, can be used to measure the effectiveness of various displays.

Consider first the weapon assignment problems. These were solved through assignment of a low explosive (L), or high explosive (H), or nuclear (N) warhead. We consider $\underline{x}$ to be the input information presented on the display ($\underline{x}$ indicates, L, H, or N) and $\underline{y}$ is the assignment made by the operator ($\underline{y}$ is also either L, H, or N). Data are collected with a display using different problems and different operators. From these, the conditional probabilities p_x (y) are determined. Thus we determine p_L (L), p_L (H), and p_L (N), the probability that when a low explosive warhead should be assigned, the operator actually assigns L, H, and N, respectively. The other conditional probabilities are also determined from the experiment.

Consider the case where for each given required weapon, the correct assignment and each of the two incorrect assignments are made equally often. Thus, p_L (L) = 1/3, p_L (H) = 1/3 and p_L (N) = 1/3, and similar results occur for p_H (L), p_H (H), etc. Assuming that unequivocal information transmission would have yielded the correct decision, then the information transmitted by this display can be shown to be:

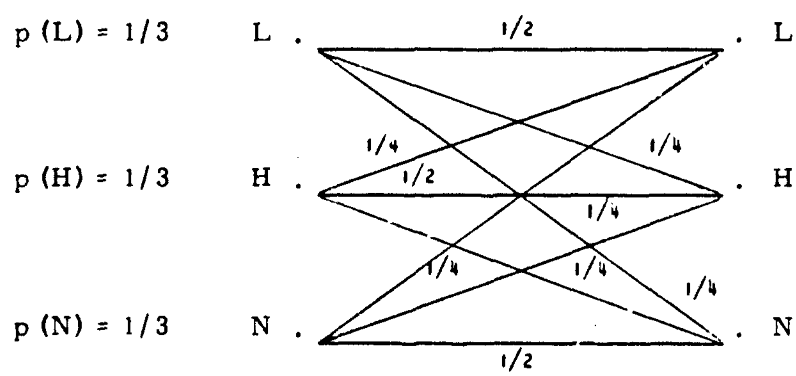
$$\log^{*} 3 - 1/3 \log 3 - 1/3 \log 3 - 1/3 \log 3 = 0$$

Here, the operator is merely guessing and the display conveys no information to him. This situation is diagrammed below:



Conditional probabilities are shown on the lines joining $\underline{x}$, the weapon which should be assigned, and $\underline{y}$ the weapon which is assigned.

The results for a second display where now the correct assignment is made with a probability of 1/2 and each of the incorrect assignments is made with probability of 1/4 follows:



The information conveyed by this display is

$$\log 3 - 1/2 \log 2 - 1/4 \log 4 - 1/4 \log 4$$

$$= 1.58 - 1/2 - 1/4 \cdot 2 - 1/4 \cdot 2 = 1.58 - 1.50 = .08$$

---

* All logarithms are to the base 2.

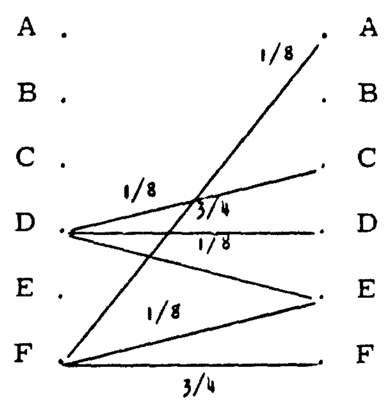
This means that out of each 158 bits of input information 150 bits are lost because of the "equivocation" of the display. Eight bits are actually conveyed to the operator.

This same type of analysis can be applied to battery assignments. Consider, for example, that there are six batteries and that each is assigned with equal probability. The input information is then $\log 6 = 2.58$. Suppose that, in the experiment, it is found that the correct assignment is made 3/4 of the time, but that the two adjacent batteries are assigned 1/8 of the time. The information conveyed by this display is:

$$\log(6) - 3/4 \log 4/3 - 1/8 \log 8 - 1/8 \log 8$$

$$= 2.58 - 3/4 (\log 4 - \log 3) - 1/4 \cdot 3 = 1.52$$

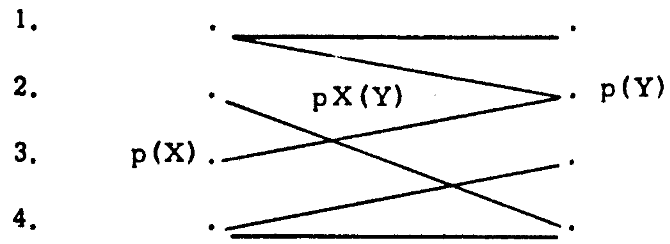
Hence, out of each 258 bits, 152 are conveyed to the operator and 106 are lost because of the ineffectiveness of the display. This situation is shown below, when the conditional probabilities are sketched in for batteries D and F.



Thus, when F should have been assigned, we assume that it was found that F was assigned 3/4 of the time but either E or A (the adjacent batteries) were each assigned 1/8 of the time.

The more general case brings Bayes theorem more in evidence, i.e., the case where the assignments are not made symetrically. For example, in the case of pictorial displays, certain biases can be expected in certain directions. This will result in unsymmetric conditional probabilities.

Let the correct answers have probabilities $p(X)$ in a given series of experiments, while the answers given by the subjects have probabilities $p(Y)$. This is shown in a diagram as follows:

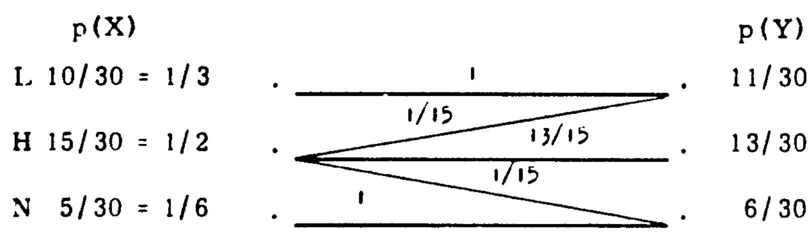


This diagram shows that when 3 should have been assigned 2 was actually assigned. The diagram also shows the conditional probability pX(Y) that when X was correct Y was assigned.

The following shows an actual experimental result for a weapon assignment problem with a given display.

	p(X)	p(Y)
L	1/3	11/30
H	1/2	13/30
N	1/6	6/30

Thirty tests were run with this display. The correct assignment in 10 of the 30 should have been the assignment of a low explosive weapon, but this weapon was actually assigned 11 times. Hence, there was one incorrect assignment of a low explosive weapon. The high explosive weapon should have been assigned 15 out of the 30 times, but it was actually only assigned 13 times. The nuclear warhead should have been assigned only five out of 30 times but it was actually assigned in six out of the 30 tests. Hence, it was also used incorrectly once out of the 30 tests. The following shows the situation more completely because in this diagram it is actually seen that the incorrect assignments should have been made to the high explosive warhead:



The diagram shows the conditional probabilities. The $p_L(L) = 1$ and $p_N(N) = 1$ since in the tests with this display, these warheads were always assigned correctly. However, when H was the input in 15 tests, it was assigned correctly 13 times ($p_H(H) = 13/15$), L was assigned once in the 15 tests, and N was assigned once in 15 tests. Hence $p_H(L) = 1/15$. It is thus seen how the diagram is derived from the test results.

Bayes formula; $p(X, Y) = p(X)\, p_X(Y)$, is now used to derive the following table:

X, Y	p(X, Y)	$\frac{p(X, Y)}{p(X)\,p(Y)}$
L, L	1/3	30/11
H, L	1, 30	2/11
H, H	13/30	2
H, N	1/30	1/3
N, N	1/6	5

In general, this table for this problem would have nine entries, but four of them did not occur in these tests, i.e., (L, H), (L, N), etc.

These are all the data required to calculate the effectiveness of the display as determined by these test results.

1. The input information to the display is

$$- \Sigma\, p(X) \log p(X)$$

$$= 1/3 \log 1/3 - 1/2 \log 1/2$$

$$- 1/6 \log 1/6 = 1.46$$

2. The information transferred by the display to the operators is

$$\Sigma\, p(X, Y) \log \frac{p(X, Y)}{p(X),\ P(Y)}$$

$$= 1/3 \log 30/11 + 1/3 \log 2/11 + 13/30 \log 2$$

$$+ 1/30 \log 1/3 + 1/6 \log 5 = 1.17$$

3. The information lost because of the ambiguity of the display = input information - information transferred = 1.46 - 1.17 = .29

Thus, out of every 146 bits of information, using this display, 117 are transferred and 29 are lost. This display $\frac{117}{146}$ = .80, or 80% efficient.

The above logic was applied to the display decision data derived in the present study. The information transferred for decision 22, a weapon launch decision, and for decisions 23 and 24, battery assignments is presented in Table 9.

Table 9

Information Transferred (in Bits) for Various Decisions

Decision	Display Type	Bits Transferred
22	Pictorial-plus-Color	1.46
	Pictorial Black-and-White	1.23
	Tabular-plus-Color	1.46
	Tabular Black-and-White	1.16
23	Pictorial-plus-Color	.43
	Pictorial Black-and-White	.99
	Tabular-plus-Color	1.25
	Tabular Black-and-White	1.10
24	Pictorial-plus-Color	1.85
	Pictorial Black-and-White	1.76
	Tabular-plus-Color	1.88
	Tabular Black-and-White	2.07

These data suggest from one point of view, that, if anything, the tabular displays were more efficient than the pictorial displays. It seems that the pictorial display gains its advantage from its relationistic presentation, not from its economy of information transfer. It will be noted that both types of display were relatively efficient for decisions 22 and 24. The advantage of color coding also becomes apparent, once again, in the current analysis.

CHAPTER III

CROSS VALIDATION

While the results of experiment I suggested the validity of the DEI technique for predicting decision ability with various types of displays, it was considered important to check the findings in an independent experiment. Moreover, while experiment I considered two decision levels, the higher or more difficult decision level, which involved such mental aspects as reasoning, memory, comprehension, and computation, was of greater interest than the lower decision level, which emphasized the ability to extract specific units of information from a display.

In experiment II, the stimuli remained the same as in experiment I. The same four display types were again employed: pictorial, pictorial-plus-color, tabular, and tabular-plus-color. Also, the same six command and control situations were again employed. However, one concern of experiment II was to emphasize the higher order decision processes. Accordingly, the questions answered by the subjects, which involved information extraction, were eliminated. Additional questions of the more complex decision making type were written into the experiment.

The number of decisions contained in each problem varied as a function of the number of threats in a problem. The total number of decision-making questions for all six problems was 102. For the less saturated (fewer threats), as few as 12 decisions were involved, while the most heavily saturated problems had as many as 25 decisions. The decision-making questions used in experiment II appear in Appendix E.

Subjects

Again, twenty male college students served as subjects. All were students at either Eastern Baptist College or Villanova University. None of the subjects from experiment I participated in experiment II.

Procedure

The subjects were randomly assigned to one of the four experimental groups--one group for each presentation technique. No one group possessed more than three subjects from a specific college.

The pay scale was the same as in the first experiment, $1.50 per hour. However, in the second experiment, the subjects were not offered

a bonus for reaching a criterion level of performance. Instead, they were allowed to place bets on their battery assignment and weapon launch decisions. As a result of these bets, they could win up to six additional dollars. The betting scheme and procedure are explained more fully below.

Virtually, the same procedure was used in both experiments. However, certain changes were introduced in order to accommodate the more extensive probability analysis that was performed on the data resulting from experiment II. Consequently, during the second session, and after the complete retraining and remedial training, the subjects were instructed on the betting procedure they were to use after reaching each weapon launch and battery assignment decision.

The following instructions were read to the subjects while they read them to themselves.

DIRECTIONS FOR USING PAYOFF TABLES

In answering questions pertaining to battery assignments and weapon launch you will be required to do two things. First, you will make the assignment; second, you will make a bet. You have sixteen cents to bet on each question. If you are very confident that the assignment you made is correct, then you may bet the entire sixteen cents on that assignment. However, you don't have to bet the whole sixteen cents on any one battery. For example, if you think that it is equally likely that the correct choice might be either of two batteries, then you would bet eight cents on each of two batteries. Or, if you think that the correct choice might be either one of two batteries and you think that the chances are 3:1 that the correct choice is one battery over the other, then you would bet twelve cents on one battery and four cents on the other. You can distribute your sixteen cents in any way you want over the eight batteries in the complex. However, the total sixteen cents must be committed on each assignment, be it battery assignment or weapon launch.

The answer sheets you will be given have spaces in which you are to mark your answers and your bets. If you divide your bet over more than one battery or weapon type, you indicate this by entering the amounts of your bet in the appropriate spaces.

The payoff tables show the amount you can win if you bet the entire sixteen cents on a given battery or weapon type and that battery or weapon is the correct choice. Since the payoff (the amount you can win) is a direct function of the payoff

table, you can determine how much you would win by taking the proportion of sixteen cents that you bet on the correct choice, and then multiply the figure shown in the table by the same proportions. For example, if battery A was assigned when it should have been and you bet the entire sixteen cents you would win fifty cents. If instead, you bet four cents on battery A when it should have been assigned, then you would win 1/4 of fifty cents or thirteen cents. If you assigned battery D when battery A was the correct choice and you bet eight cents on battery D, then you would win 1/2 of twenty cents or ten cents.

Money will not be on the line for every assignment you have to make. However, since you will not know for which assignments money is on the line, you should treat each assignment as though money were on the line. You can win up to one dollar for each command and control display you are shown, in addition to your base pay. Since you will be questioned on six different command and control displays, you can win up to six dollars. You will be asked questions other than battery assignment and weapon launch. As far as the other questions are concerned, you can win three cents for each correct answer. In no case will you lose any money.

All questions were answered fully after the instructions were read and then the experiment began.

The payoff table was arranged to yield a decreasing payoff as the assignment made got further from the assignment that should have been made.

Money never changed hands during the experiment. The sixteen cents the subjects had to bet on each weapon launch and battery assignment decision was a bet on paper only. At the conclusion of the experiment, the winnings were calculated.

Two sessions were held with each group. The first session, in which the subjects were introduced to the problem and the initial training that was presented lasted two hours. The second session which involved retraining and data collection took approximately four hours.

The presentation sequence, and exposure intervals, for the stimuli remained the same as in experiment I.

Results and Discussion

The subjects' decision scores were determined and sorted according to the variables of interest, display type and threat numerosity within display type. Since there was a different number of decisions to be made in the various problems, the decision scores were converted into percentages. The data were subsequently subjected to several analyses, as discussed below.

An analysis of variance was performed on the decision scores. However, because the values were now expressed in terms of proportions, the proportions were transformed into angles or arcsins (Walker and Lev, 1953) for the variance analysis.

Table 10, the summary table of the variance analysis, indicates a statistically significant difference among display types ($p < .01$). Application of Tukey's test for significant differences among treatment means resulted in significant differences among the pictorial-plus-color (with the highest mean decision score) and both tabular displays, and between the pictorial black-and-white and the tabular black-and-white. However, the two tabular displays did not differ significantly from each other and the pictorial black-and-white did not differ significantly from the tabular-plus-color. Figure 9 presents the mean decision scores for each display type. Here, an almost perfect linear relationship between decision score and

Table 10

Summary of Analysis of Variance for Experiment II

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Problems (P)	.63	5	.13	1.18
Display Types (DT)	1.29	3	.43	4.00*
P x DT	2.09	15	.14	1.27
Error	10.24	96	.11	
TOTAL	14.25	119		

display type is evidenced. With each of the two major display types, the effect of color was to enhance the decision score. When color was added to the pictorial display type there was an increase of six percent in the

*Significant at or below the .01 level of confidence

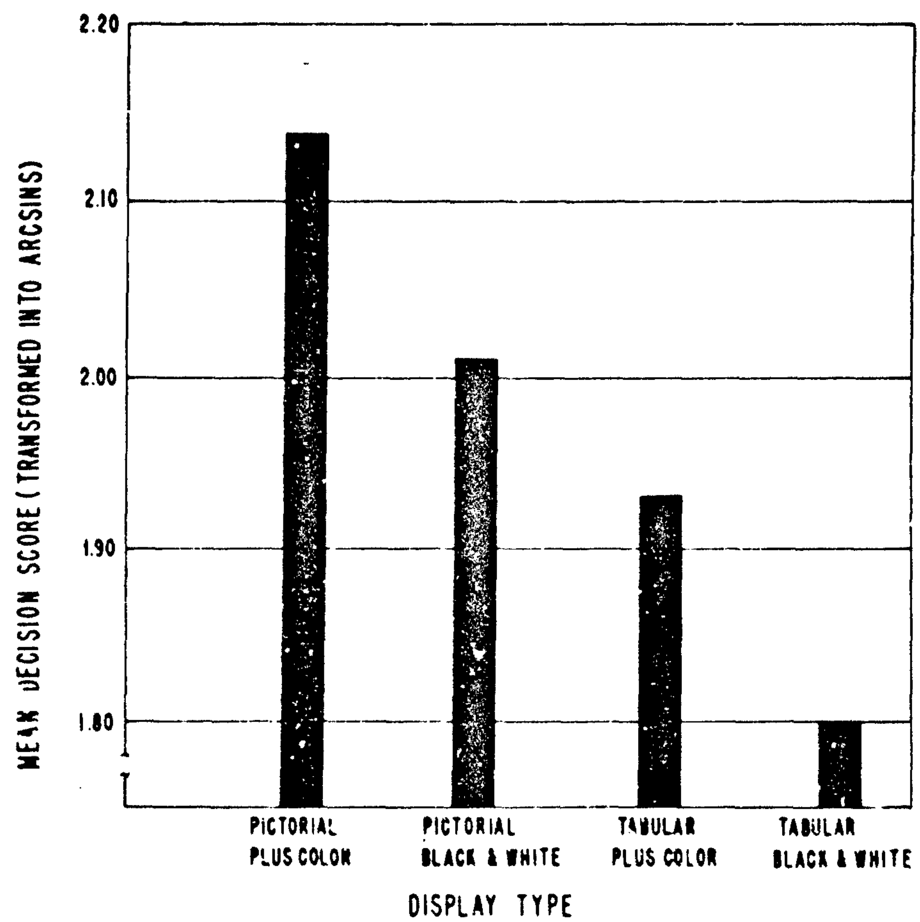


FIGURE 9. DECISION SCORE AS A FUNCTION OF DISPLAY TYPE.

decision score. Similarly, when color was added to the tabular display type there was an increase of seven percent. The plot also shows the relative superiority of the pictorial displays over the tabular displays, for the decisions involved. The effects of color and the effects of the two major display types (disregarding color), pictorial and tabular, upon decision scores are indicated for each stimulus situation in Figures 10 and 11.

With the exceptions of stimulus 1 (an "easy" problem) and stimulus 5 (a "difficult" problem) in Figure 11, color was always a facilitating agent. The mean (arcsin) decision score for color across all problems was 2.04, whereas the mean (arcsin) decision score for the black-and-white displays was 1.91.

In no instance did the tabular displays, including both color and black-and-white, yield higher decision scores than the pictorial displays, including both color and black-and-white (Figure 11). The pictorial displays had an overall mean decision score (arcsin) of 2.08, while the tabular displays had an overall arcsin mean decision score of 1.87.

Generally, the stimulus situations possessing the greater number of threats (higher numbered stimulus situations) yielded lower decision scores, a finding in conformity with the results of experiment I.

Application of the DEI Technique

The Display Evaluative Index technique was applied to the six stimulus situations and four display types, resulting in 24 DEI values. The resulting DEIs are presented in Table 11. The values are ranked hierarchically from high to low in both rows and columns. From Table 11 the effect of stimulus situation (problem) and display type can be seen from the point of view of the DEI technique. The "easy" problems, with fewer threats, yielded higher values than the more dense displays or "difficult" problems. This finding is in accordance with the empirically derived decision scores described above. Similarly, the pictorial displays were ranked above the tabular displays, and within each display type the color displays were evaluated as being superior to their black-and-white counterparts. These findings are also in accordance with the objective decision scores.

Correlational Analyses

The relationship between the calculated DEIs and the empirical results of the experiment was calculated. Pearson product moment

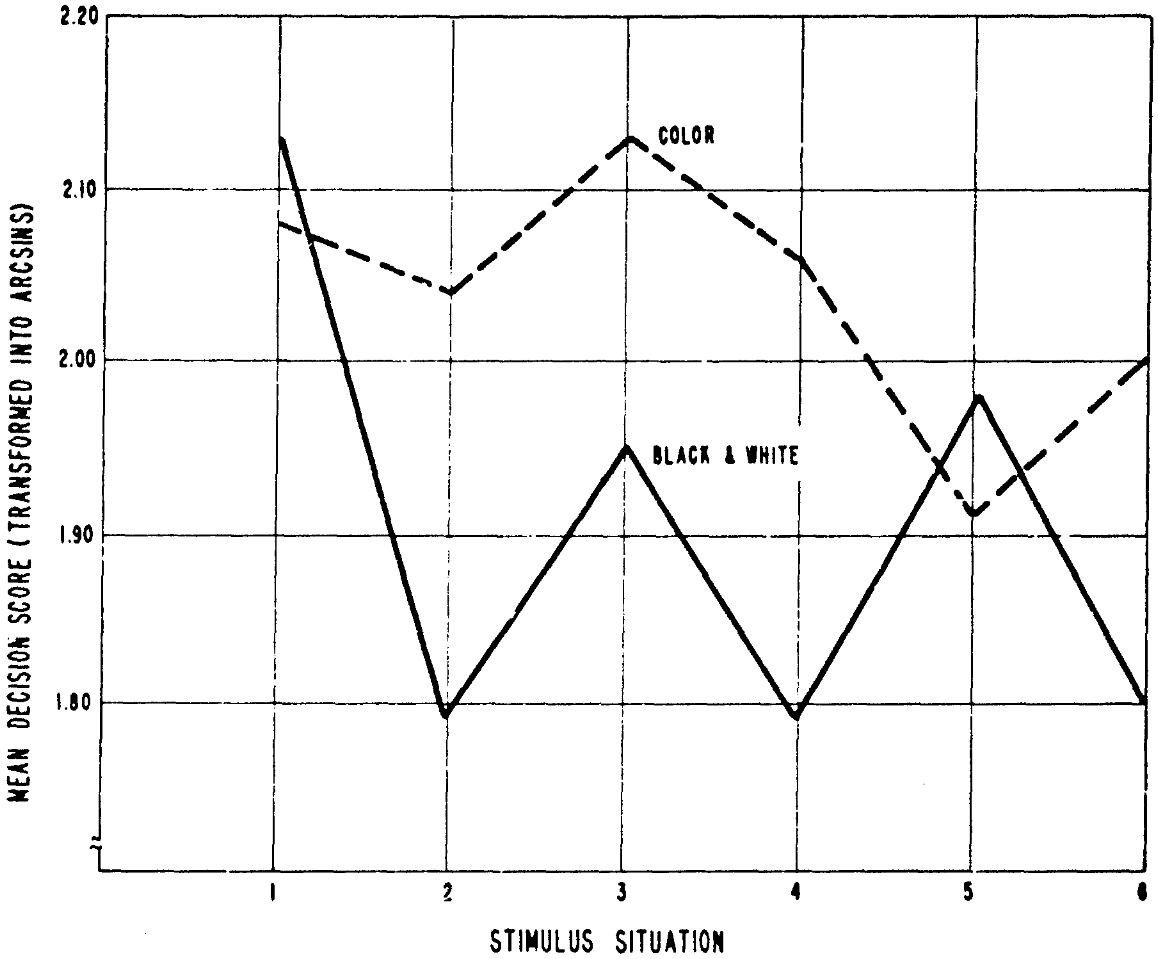


FIGURE 10. DECISION SCORE AS A FUNCTION OF COLOR.

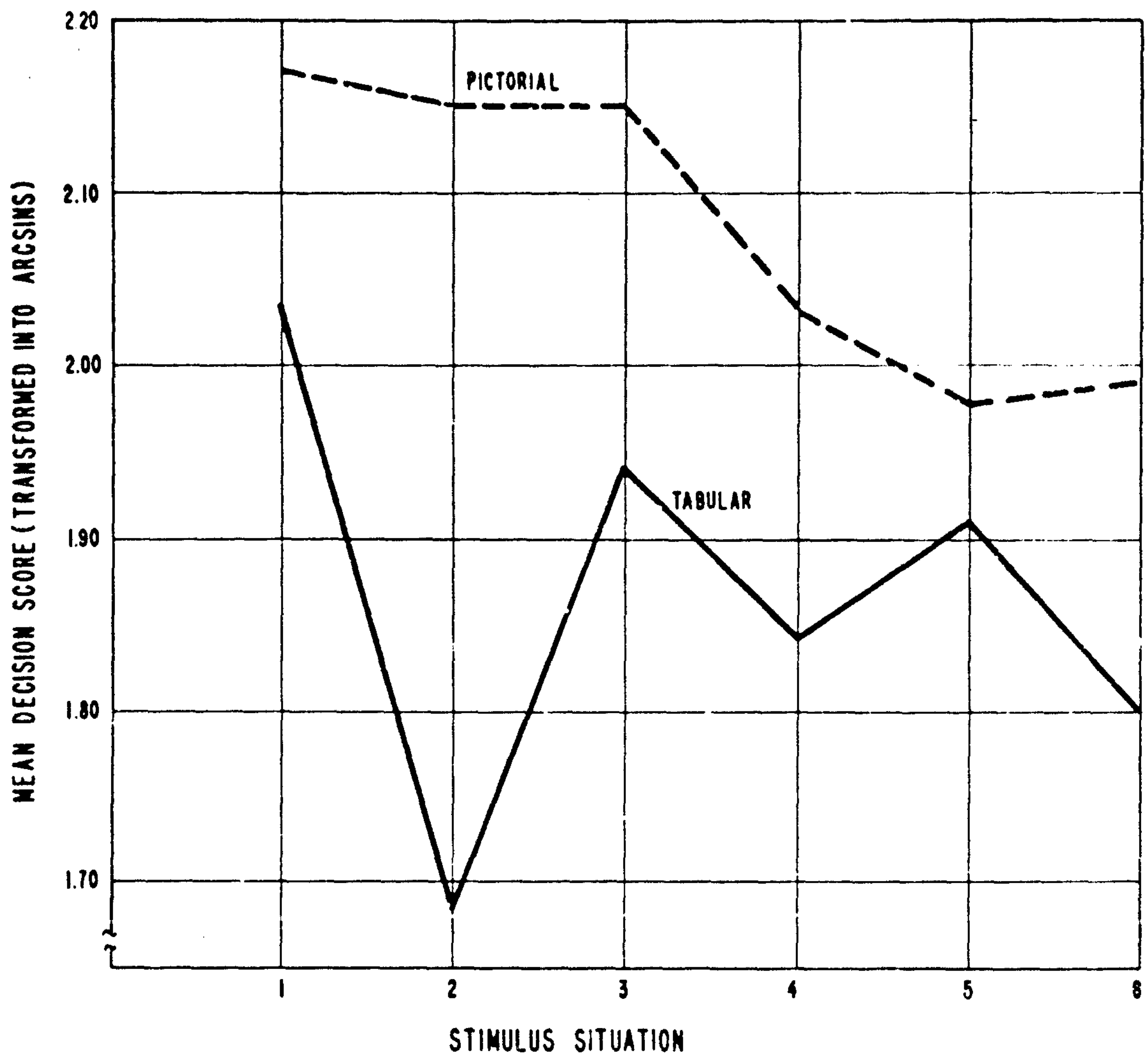


FIGURE II. DECISION SCORE AS A FUNCTION OF STIMULUS SITUATION.

correlation coefficients were obtained between the decision scores and the DEI values for each display type within each problem and across all problems. The results of the correlational analyses are presented in Table 12.

Table 11

DEI Rank Order of Problems and Display Types

Problem	Pictorial-plus-Color	Pictorial Black-and-White	Tabular-plus-Color	Tabular Black-and-White
1	.285	.248	.236	.232
2	.253	.233	.215	.205
3	.179	.154	.139	.133
4	.132	.123	.098	.097
5	.123	.111	.098	.097
6	.088	.080	.068	.065

Table 12

Product Moment Correlation Coefficients Between DEI Values and Decision Scores

Problem	Correlation	p
Overall	.54	<.01
1	.44	<.05
2	.06	----
3	.45	<.05
4	.40	----
5	-.01	----
6	.31	----

From Table 12 it can be seen that for all display types and across all problems, an adequate relationship ($r = .54$) was found to exist between the DEI and the decision scores. The significant level for this correlation coefficient ($p < .01$) allows the null hypothesis ($r = 0$) to be rejected and, hence, the acceptance of the hypothesis that a positive correlation did, in fact, exist between the DEI values and the decision scores.

Confidence or Reasonableness of Betting Patterns

The subjects in this experiment were asked to decide upon the weapon and battery to assign to each of a certain number of threats. Furthermore, they were to distribute a total of 16 cents in bets over the various weapon and battery assignments, for each threat. It was strongly hinted that the subjects would do best if they distributed their bets in proportion to the probabilities of, or their confidence in, their choice. In reality, while this may not have been the optimal strategy, it had one advantage, viz., it might minimize the variation in the payoff for each trial. As will be seen later, the maximum expected payoff is obtained by always betting all the money (16 cents) on the most likely event (that with highest probability), if that is known. Then on any particular trial, the payoff is maximum (50 cents) and the average (expected value) is highest. If a wrong guess resulted in zero payoff, then to minimize the range of values it would be necessary to distribute the bet over all the possibilities. By spreading the bet over several reasonable possibilities a lower bound can be set on the gain at each trial. Therefore, the total gain is at least n times this lower bound, where n is the number of trials. The latter strategy is a conservative one.

To measure deviations from this strategy, the following formula was devised:

$$R = 1-1/2 \, \Sigma \left| p_i - b_i \right|$$

where R might be called the reasonableness or rationality of the subjects in following a conservative strategy, p_i is the probability or relative certainty in the mind of the subject that weapon or battery i is the correct one, and b_i is the fractional part of the total amount (16 cents) that is placed on choice i. If the distribution of the total amount of money is in proportion to the probability of the events, then $p_i = b_i$ for all i.

Then $p_i - b_i = 0$ for i and R = 1. A few illustrations are given in the example below. The example on the first line assumes it to be equiprobable (p = .5) that battery D or E should be chosen (is the correct one). The money is equally distributed over these possibilities and R = 1. In examples 5 and 6, no money is placed on possible choices ($p_i > 0$). These would represent cases of entire lack of reasonableness or lack of rationality so that R should be zero.

Example	A p, b	B p, b	C p, b	D p, b	E p, b	F p, b	G p, b	H p, b	$\Sigma \lvert p_i - b_i \rvert$	R
1	0,0	0,0	0,0	.5,.5	.5,.5	0,0	0,0	0,0	0	1
2	0,0	0,0	1,1	0,0	0,0	0,0	0,0	0,0	0	1
3	0,0	.2,.2	.3,.3	.3,.3	.2,.2	0,0	0,0	0,0	0	1
4	.1,0	.3,.2	.4,.3	.2,.4	0,.1	0,0	0,0	0,0	.6	.7
5	0,.2	.3,0	.2,0	0,.3	0,.4	.2,0	0,.1	.3,0	2	0
6	0,0	0,0	1,0	0,1	0,0	0,0	0,0	0,0	2	0
7	0,0	.1,.2	.1,.5	.6,.2	0,0	.2,0	0,.1	0,0	1.2	.4
8	0,0	0,0	0,0	0,0	0,0	1,.5	0,.4	0,0	.8	.6

Examples 2 and 6 illustrate the cases most often encountered in the present project. In example 2, the subject placed 16 cents on C which was the correct battery ($p_c = 1$), R = 1. In example 6, the subject place 16 cents on battery D which was wrong ($p_d = 0$) so R = 0. If subjects never split their bets, then R would be either 0 or 1.

So far, the payoff function has not entered into the computation. The implicit assumption was that it is reasonable, i. e., that the reward for the correct answer is maximum and that for incorrect answers the reward is less than maximum or even zero. The latter is usually the case.

In the present project the subjects were shown the payoff table before the trials began. The payoff was 50 cents for a correct answer, if all 16 cents was bet on that choice, or an amount proportional to the actual bet. Thus, if 12 cents was bet on the correct answer, the payoff was 12/16 x .50 = 38 cents. If the total 16 cents was bet on a wrong battery, adjacent to the correct one, the payoff was 40 cents; if the total was placed on a wrong battery two positions from the correct battery, the payoff was 30 cents, and so on. This payoff distribution might tend to encourage a subject to bet all on the most probable battery, since he would still probably obtain a reward in a particular trial in which this battery was not correct. Suppose the payoff was the same for all batteries, correct or incorrect. Then any answer would yield the same reward. This would encourage guessing and eliminate effort on the part of the subject. The present triangular distribution, to the extent it approaches a constant payoff function, may have produced a similar effect. This may be justified in that it reduces stress in the subject and still offers some incentive to do well. The other extreme would be to place a penalty (negative payoff) on wrong answers.

To illustrate the effect of spreading a bet, we assume the following examples with the batteries under consideration limited to D, E, and F:

Example	D p	D b	E p	E b	F p	F b	Expected Payoff	Min. Payoff	Max. Payoff	R
a	.2	.2	.6	.6	.2	.2	43.6	40	46	1.
b	.2	0	.6	1.	.2	0	46.0	40	50	.5
c	.3	.3	.4	.4	.3	.3	41.6	40	44	1.
d	.3	0	.4	1.	.3	0	44.0	40	50	.4
e	.3	.3	.4	.3	.3	.4	41.2	39	41	.9
f	.3	.2	.4	.3	.3	.5	38.2	27	43	.8

The payoff is given by:

		Assigned D	Assigned E	Assigned F
Should	D	50	40	30
have	E	40	50	40
assigned	F	30	40	50

In example f, R = 8. If D is correct, then the expected payoff is $50\ b_D + 40\ b_E + 30\ b_F = 10 + 12 + 15 = 37$ cents. If E is correct, then the payoff is $40\ b_D + 50\ b_E + 40\ b_F = 8 + 15 + 20 = 43$ cents. If F is correct, then the payoff is $30\ b_D + 40\ b_E + 50\ b_F = 6 + 12 + 25 = 43$ cents. D is correct .3 of the time, E is correct .4 of the time, and F is correct .3 of the time. The expected value of payoff when the bets are always distributed in the same ratio (2:3:5) is

$$E = p_D (27) + p_E (43) + p_F (43) = .3 (27) + .4 (43) + .3 (43) = 8.1 + 17.2 + 12.9 = 38.2$$

In general,

$$E = p_D (50\ b_D + 40\ b_E + 30\ b_F) + p_E (40\ b_D + 50\ b_E + 40\ b_F) + p_F (30\ b_D + 40\ b_E + 50\ b_F)$$

$$= 50 (p_D b_D + p_E b_E + p_F b_F) + 40 (p_D b_E + p_E b_D + p_E b_F + p_F b_E + 30 (p_D b_F + p_F b_D)$$

In example f, the maximum payoff is 43 cents (when either E or F is correct) and the minimum gain is 27 cents (if D is correct). Examples c to f have the same probability distributions but varying bet distributions. In example c, the distributions are the same (conservative). The payoffs are either 40 cents or 44 cents each time, with the expected value 41.6 and R = 1. In example e there is a slight change in the bet distribution among E and F. Minimum and maximum payoffs are 39 cents and 41 cents. However, the expected value has dropped to 39 cents and R to .9. The best bet distribution is in example 4 with all on E, the most probable. The minimum and maximum values are now 40 cents and 50 cents while the expected value has reached 44 cents which is the maximum attainable for any bet distribution. The R value has decreased to .4 indicating there is considerable deviation from the equality of the distributions.

The R value for each answer for each subject was computed through a comparison of the subject's bet distribution with what the subject reported separately as his answers (regardless of the correctness of the answer). The resultant R value is considered to reflect the subject's confidence in his answer and/or the reasonableness of his bet pattern.

The average R values for battery assignment are given below:

Display	S1	S2	S3	S4	S5	Overall Average
TBW	.94	1	.96	1	.83	.95
TC	1	.92	1	.94	.89	.95
PBW	1	1	1	.91	.89	.96
PC	.89	.98	1	.99	.87	.95

The average R values for weapon assignment are given below:

Display	S1	S2	S3	S4	S5	Overall Average
TBW	.94	1	.92	1	.77	.93
TC	1	1	1	.95	.89	.97
PBW	1	1	1	.98	.91	.98
PC	.88	1	.94	.98	.99	.96

These results indicate that most of the subjects were consistent, i.e., they placed all 16 cents on the possibility they thought was the correct one. In view of the nature of the payoff table this turned out to be the most

reasonable strategy. However, it appears that the subjects were also somewhat overconfident. The decision scores, reported earlier, were not accurate in many cases. There is no indication in the data that the subjects were more reasonable with one type of display, than with another.

Probability or Information Transfer Analysis

The probability, or information transfer analytic method, described in the last section of Chapter II, was applied to the findings of the second experiment. The results, tabulated across subjects and decisions, are presented in Table 13.

Table 13

Information Transferred (Bits) for Each Display Type

Problem Type	Display Type	Bits Transferred
Battery Assignment	Pictorial-plus-Color	1.86
	Pictorial Black-and-White	1.76
	Tabular-plus-Color	1.91
	Tabular Black-and-White	2.08
Weapon Launch	Pictorial-plus-Color	1.03
	Pictorial Black-and-White	.95
	Tabular-plus-Color	1.13
	Tabular Black-and-White	.65

The findings, indicated in Table 13, are consistent with the results of the first experiment, as presented in Table 9. The battery assignment tabulation of Table 13 is based on a total of 27 decisions per subject or 135 decisions per display type. For the weapon launch tabulation, 33 decisions per subject were involved. Thus, a considerably greater number of decisions is represented by Table 13 as compared with Table 9, in which three decisions per subject are involved. Even with the increase in the number of decisions involved and with the addition of a risk function in experiment II, from the point of view of the information transfer analysis, no significant superiority is found for the pictorial presentation. As in experiment I, some value is indicated in the use of redundant color coding. Thus, again, it seems that the effectiveness of the pictorial displays is not so much in their efficiency of information presentation, but in their ability to help the user to deal with relationships in context.

CHAPTER IV

DISCUSSION, SUMMARY, AND CONCLUSIONS

The principle purpose of the current set of studies was to investigate the effectiveness of the DEI technique for predicting the effectiveness of large scale displays. The findings suggest that DEI values for a set of displays do, in fact, correlate with objective decision quality scores for decisions made on the basis of information displayed in various ways. It was also indicated that the DEI technique may be considered to be a better predictor for decision-making scores than for information-extraction scores. As the result of this tendency, experiment II seemed to yield greater correlations between the DEI values and the objective scores, than did experiment I. The principle difference in experiment II, as compared with experiment I, was in the number of decision-making questions involved. In experiment II, no information extraction decisions were involved, while in experiment I, each subject's total decision score was based on both information extraction and decision-making items. A superiority in the ability of the DEI technique to predict the decision-making, as opposed to the information extraction, situation was predictable. The DEI technique is purported to yield an evaluative measure of the display reading ⟶ decision making ⟶ control activation links in a man-equipment system. Thus, the DEI technique was designed to measure certain elements of the decision-making aspects of man-equipment operations.

The factors in the pictorial display type which were influential in yielding higher DEI values were the lower mismatch factor, the lower number of elements, the fewer links involved. The tabular displays presented information to three significant figures. This was true for information items such as range, altitude, and range rate. However, application of the decision rules to make a battery assignment only required relative judgment of distance and general knowledge of altitude (greater or less than 10,000 feet) and range rate (inside missile range at present or within 15 seconds).

Due to the increased simplicity of the pictorial type display, it possessed fewer links and it required fewer information transforms and conversions. Thus, the pictorial displays received a better directness score, a lower complexity value, and a higher data transfer factor score.

The finding which indicated superiority for the displays involving redundant color coding, at least at the higher decision making level, was also to be anticipated and supports and extends the findings of others (Hitt, 1961; Smith, Farquhar, and Thomas, 1965). Smith, Farquhar, and Thomas

found that color added to the ability to perform counting and comparison operations in formated (tabular) displays. Hitt's results indicated color-coding to be superior to other types of coding (alpha-numerical, shape, etc.) for several types of tasks. On the other hand, the results of Silver, Landis, and Jones (1965) yielded an indication that for the redundant color situation, a color redundant by fact interaction existed. The authors fail to explain this finding. We prefer to interpret our findings as supporting the principle within the DEI which stated that information transfer effectiveness will increase if provision is made for redundancy of information.

In experiment I, statistically significant differences were found between the decision scores resulting from high and low density (target numerosity) situations. These differences were also reflected by the DEI values. This indicates that the DEI is sensitive to difficulty level. This finding further supports arguments favoring the sensitivity of the DEI. It is pointed out that this type of employment of the DEI technique represents something of an extension of the technique, since, at the outset, the technique was not purported to differentiate between difficulty levels within a display but only to discriminate between different display designs. The finding that as fact density (threat numerosity) increased, decision scores decreased, is in accordance with the findings of previous investigators (Silver, Landis, and Jones, 1965). However, the present study extends this previous work by pointing out that increasing fact density debilitates complex decision-making to a greater extent than it debilitates information extraction.

We hypothesized that the pictorial displays would yield better scores for decision level II, involving complex dec sion-making, but that the tabular displays would be found more facilitative for the extraction of simple facts such as system status, availability of units, absolute quantitative level, and the like. The results of experiment I tended to support this hypothesis. The tabular displays were superior to the pictorial displays for decision level I and the reverse held for decision level II. When the results of both levels were grouped, the pictorial displays seemed superior. In the second experiment, which emphasized decision level II, the pictorial type of display yielded higher decision scores. This finding held across problem difficulty levels and whether redundant color was or was not involved.

The information transfer analyses tended to point out that different methods will tend to produce different (and possibly antithetical) indications, regarding the utility of a given display or set of displays. While the pictorial displays seemed to produce higher decision scores, the tabular displays appeared to be more efficient. This finding seemed to hold for both experiment I and experiment II. Thus, it seems that different evaluative methods must be used in any display evaluation that purports to be complete. If decision-making optimization is desired, then the DEI technique results will probably

yield the required information. On the other hand, if information transfer efficiency best represents the required result, then alternative evaluational techniques are probably needed.

Our analysis of the reasonableness of the betting patterns again points up the importance of a number of measurement techniques for evaluating displays. The betting patterns of the subjects did not appear to differ across the display types. The subjects tended to place their total bet allocation, for any single trial, on the possibility which they believed to be most correct. Hence, the rationality of the betting patterns failed to discriminate among display types. However, it is probably a truism that a display which yields a low R value (which we interpret as an index of subject reasonableness in employing the display or confidence in his decision based on the information transferred by the display), will be less desirable than a display which yields a high R value.

The impetus for the current study was the need for a technique for evaluating large scale displays while the displays are in the conceptual phase of development. Previous studies established the validity of the technique for predicting display reading → information processing → control action situations with smaller displays of other natures. The results of the present work support the contention that the technique possesses adequate power to discriminate between displays of different designs and to predict the ability of persons to make decisions on the basis of the displays when large scale screen displays are involved. The technique is objective, quantitative, and possesses acceptable reliability. As such, it seems that the DEI technique will, at least partially, fill the gap which motivated the present work. It is not our contention that the technique is a substitute for static or dynamic mock-up evaluations or other human factors evaluative techniques. We do maintain, however, that the technique will be useful for hierarchically ordering alternate techniques for displaying information when the various techniques are in the conceptual phase. Quite obviously, the technique does not consider engineering feasibility, cost, and human engineering principles of the check-list variety. Improvements to the technique remain possible, especially from the information extraction point of view.

Summary and Conclusions

Two experiments were performed in order to investigate the relationship between the values yielded by the Display Evaluative Index technique, a technique for evaluating the ability of displays to transfer information to the operator and for the operator to act on this information, and objective scoring of decisions based on these displays. Other purposes of the work

included: (1) comparison of the effectiveness of pictorial and tabular displays from the decision correctness and the information extraction points of view, (2) investigation of the advantages, if any, of redundant color coding in a display, (3) investigation of the information transfer efficiency of pictorial and tabular displays, (4) investigation of the effect of fact density on decision scores, and (5) investigation of the reasonableness of the betting pattern or the confidence produced by different display types.

Four display types were prepared and the same six command-control stimulus situations were represented on each display type. The display types were pictorial, tabular, pictorial-plus-color, and tabular-plus-color. The six command-control situations represented an increasing order of fact density or difficulty. In each experiment, a separate group was trained in reading, interpreting, and applying the information of each display type. Each group was then exposed to the display type on which it had been trained and its ability to use the display determined. Experiment I differed from experiment II mainly in its emphasis on obtaining both an information extraction and a decision-making score. In experiment II, only decision-making scores were involved. Display Evaluative Index technique values were calculated separately for each display.

The following conclusions seem warranted by the data:

1. The Display Evaluative Index (DEI) technique values were adequately predictive of the objective decision-making scores.

2. The Display Evaluative Index technique values were less adequate for predicting information extraction scores.

3. Pictorial displays were generally superior to tabular displays for decision-making; for information extraction this superiority did not seem to hold.

4. Color redundancy seemed to increase the ability of both tabular and pictorial displays to transmit information, at least at the higher decision level. Adding color to the pictorial displays seemed to exert a greater positive effect than did the addition of color to the tabular displays.

5. Although the pictorial display type seemed to produce higher decision scores than the tabular, the efficiency of the pictorial display, in terms of minimizing information equivocation, seemed to be less than that of the tabular display.

6. Increasing information redundancy increased information extraction scores.

7. Increasing fact density yielded lower decision-making and information extraction scores. However the effect on decision making scores seemed to be greater than the effect on information extraction.

8. In terms of the index employed, no difference was noted between the betting patterns and the operator confidence emerging from employment of the four display types involved.

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APPENDIX A

QUESTIONS FOR COMMAND AND CONTROL SITUATIONS

Experiment I

QUESTIONS FOR COMMAND AND CONTROL SITUATIONS

1. How many batteries are unassigned?

2. How many batteries are ready for assignment but not yet assigned?

3. How many batteries in the Washington-Baltimore complex are assigned?

4. How many batteries in the Philadelphia complex have launched missiles?

5. What is the total number of nuclear weapons that have been launched prior to the present situation?

6. What is the total number of high explosive weapons available for the Washington-Baltimore complex?

7. How many batteries in the Washington-Baltimore complex have more than five low explosive weapons?

8. How many batteries in the Philadelphia complex have ten or more hits?

9. How many threats are above 29,999 feet?

10. How many kill probabilities have been computed at .50 or more?

11. How many threats contain between 2 and 9 targets?

12. How many unassigned threats are inside the missile ranges, or will be inside the missile ranges within the next fifteen seconds?

13. What is the total number of unassigned threats in the northeast, as determined from each complex?

14. How many threats contain nuclear warheads?

15. How many threats are on headings of between 181° and 270°?

16. Which type of weapon has been launched most frequently in the Philadelphia complex prior to the present situation?

17. How many threats are at actual distances of 175 miles or more from the Philadelphia complex? (Exclude threats assigned to the Washington-Baltimore complex).

18. How many threats are in regions of rain?

19. How many threats are in regions where the winds exceed 20 mph?

20. How many computers are ok?

21. Which threat should be assigned next?

22. Which weapon should battery _____ launch against threat _____?

23. To which battery should threat _____ most probably be assigned?

24. To which battery should threat _____ most probably be assigned?

25. What is the overall probability of kill across all threats?

26. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?

27. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?

28. Which battery(ies), if any, selected an improper missile to launch? (Answer "None," if appropriate).

29. Assuming a wind shift of 180^{o}, for which threats would you select a different missile to launch? (Answer "None," if appropriate).

30. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

APPENDIX B

CODES FOR PICTORIAL AND TABULAR DISPLAYS

CODING FOR PICTORIAL--BLACK AND WHITE DISPLAYS

Applied Psychological Services
Science Center
Wayne, Pennsylvania

I. Threat Status

A. Threat number:

1. Threat numbers range from 01 to 15

2. If threat number begins with the numeral 5, the threat contains a nuclear warhead, e. g., 58

B. Battery assigned:

If an arc (⌒) appears above the threat number the threat has been assigned to a battery

C. Altitude:

1. • = 0 - 14,999 feet

2. : = 15,000 - 29,999 feet

3. ⋮ = 30,000 - 49,999 feet

4. ⁞ = 50,000 feet and over

D. Missiles launched:

1. = low explosive weapon

2. = high explosive weapon

3. = nuclear weapon

E. Actual position and threat size:

1. The position of the circle indicates the actual or present position of the threat, as measured in miles from the center of the complex

2. ● = single target (1)

3. ○ = few targets (2 - 9)

4. ◎ = many targets (10 or more)

F. Predicted range:

Indicates predicted position of threat after 15 seconds, as measured in miles from the center of the complex

G. Directional line:

Indicates relative direction in which threat is heading

H. Predicted intercept point:

Indicates the point at which the threat will be intercepted by the battery launched weapon

I. Battery assigned:

Indicates the battery assigned to the threat

J. Missile ranges:

Indicates maximum range of the missiles used by batteries--radius of missile range equals 150 miles

K. Battery designators:

1. Batteries A through H represent the eight batteries surrounding the Philadelphia complex

2. Batteries I through P represent the eight batteries surrounding the Washington-Baltimore complex

L. Weather indicators:

1. = clear
2. = rain
3. = snow
4. = wind direction
5. = full barb equals 10 mph
6. = 1/2 barb equals 5 mph

M. Complex designators:

1. = Philadelphia
2. = Washington-Baltimore

II. Battery Status

A. = ready for assignment

B. = assigned

C. = missile type launched

D. Kill probability:

1. = 1.00
2. = .25
3. = .50
4. = .75

III. Weapons Available and Missile Types Launched

A. = nuclear

B. = high explosive

C. = low explosive

CODING FOR TABULAR--BLACK-AND-WHITE DISPLAYS

Applied Psychological Services
Science Center
Wayne, Pennsylvania

I. Threat Status

A. Threat number:

1. Threat numbers range from 01 to 15

2. If threat number begins with the numeral 5, the threat contains a nuclear warhead, e.g., 58

B. Threat size

1. Single = 1 target

2. Few = 2 - 9 targets

3. Many = 10 or more targets

C. Altitude:

Indicates altitude of the threat, in feet

D. Actual range:

Indicates the actual or present range of the threat, as measured in miles from the center of the complex

E. Predicted range:

1. Indicates predicted range of threat after 15 seconds, as measured in miles from the center of the complex

2. The missile ranges indicate the maximum range of the missiles used by the batteries--radius of missile range equals 150 miles

F. Complex:

Two complexes are involved--Phila and Wash; each complex consists of eight batteries and all distance measurements are made from the center of the complex

G. Battery assigned:

Indicates the battery to which the threat is assigned; batteries A through H are the eight batteries surrounding the Philadelphia complex, and batteries I through P are the eight batteries surrounding the Washington-Baltimore complex

H. Missiles launched:

1. *L* = low explosive
2. *H* = high explosive
3. *N* = nuclear

I. Actual heading:

Indicates the polar heading of the threat in degrees, as measured from the actual or present position of the threat

J. Predicted heading:

Indicates the polar heading of the threat in degrees, as measured from the predicted position of the threat after 15 seconds

K. Actual coor'd:

Indicates the present position of the threat in terms of compass bearings, e.g., N, NE, E, SE, S, SW, W, and NW

L. Predicted coor'd:

Indicates the predicted position of the threat in terms of compass bearings, e.g., N, NE, E, SE, S, SW, W, and NW

M. Intercept point range:

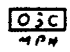
Indicates the distance, in miles from the center of the complex, at which the threat will be intercepted by the battery launched weapon

N. Intercept point coor'd:

Indicates the position of the intercept point in terms of compass bearings, e.g., N, NE, E, SE, S, SW, W and NW

O. Weather indicators:

1.  = wind direction

2.  = wind speed

3. Weather conditions box ☐ = clear, rain, snow

II. <u>Battery Status</u>

A. Coor'd = compass bearings of the batteries, e.g., N, NE, E, SE, S, SW, W, and NW

B. Des = battery designators--A through H and I through P

C. ■ = ready for assignment

D. Assigned = Y = yes, N = no

E. L, H, N = missile type launched

APPENDIX C

GROUND RULES FOR DECISION-MAKING

GROUND RULES

Applied Psychological Services
Science Center
Wayne, Pennsylvania

I. For Selecting the Weapon to Launch

A. Nuclear weapons are used when all of the following conditions exist:

1. The wind is not in the direction of the complex

2. The threat has a few targets (2 to 9) or many targets (10 or more)

3. The threat contains a nuclear warhead

4. The threat is above 14,999 feet

5. The intercept point is, or will probably be, more than 50 miles from the center of a complex

B. High explosive weapons are used when the following conditions exist:

1. The threat contains a few targets (2 to 9) or many targets (10 or more)

2. The intercept point is, or probably will be, more than 50 miles from the center of a complex

C. Low explosive weapons are used when the following conditions exist:

1. The threat contains a single target and/or

2. The intercept point is, or probably will be, within 50 miles of the center of a complex

II. For Assigning Batteries to Threats

A. The computer status must be o. k. for at least one computer in a complex before assigning a battery in that complex to a threat.

B. Threats are assigned to the nearest unassigned battery with at least five of the appropriate weapon type available. If there are two batteries equidistant from the threat and each has at least five of the appropriate weapon available, that battery is selected that has the highest batting average. Batting average is determined by using the following formula.

$$\text{Batting Average} = \frac{\text{Hits}}{\text{Misses} + \text{Aborts}}$$

C. Two batteries are always assigned to a single threat when the threat is within 30 miles of the center of the complex and the survival probability of the threat is .75 or greater (survival probability = 1 — kill probability). This assignment has the highest priority--it must be made before any other assignment. Moreover, rather than the nearest unassigned battery, the choice of battery to receive the assignment is made so as to maximize kill probability. Therefore, the unassigned battery with the highest batting average and with at least five of the appropriate weapon type availabe is selected.

D. When the kill probability is not given, the best estimate is .50.

III. For Assigning One Battery to More than One Threat

A. A battery should receive an assignment of more than one threat if all the other batteries are either assigned or not ready to receive an assignment.

B. The batteries to receive multiple threat assignments are selected on the basis of

1. the nearest with at least five of the appropriate weapon type

2. the highest batting average

C. A battery that has launched a weapon against a threat is still engaged and assigning this battery to another threat is considered a multiple threat assignment

IV. For Determining the Weather Conditions Around a Threat

Use the weather forecast closest to the threat

V. For Reassigning Threats when Both Computers Fail

If both computers fail for either complex, only those threats that are within the missile range of the other complex should be reassigned to that complex

APPENDIX D

SYMBOL TEST FOR PICTORIAL AND TABULAR DISPLAYS

SYMBOL TEST FOR PICTORIAL--BLACK AND WHITE DISPLAYS

Applied Psychological Services
Science Center
Wayne, Pennsylvania

Name______________________________ Date______________

1. What altitudes are indicated in the following codes?

   A. ⋮ Answer ______

   B. : Answer ______

   C. • Answer ______

   D. ⁞ Answer ______

2. What is indicated in the following codes?

   A. ⌒ Answer ______

   B. ◡ Answer ______

   C.  Answer ______

   D.  Answer ______

3. What is indicated when a threat number begins with the numeral 5?

   Answer ______

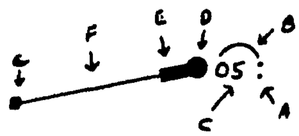
4. What is represented by the following symbols?

   A. ● Answer ______

   B. ○ Answer ______

   C. ◎ Answer ______

5. Which of the following symbols indicates (respond with the appropriate letter)



A. an assigned threat? Answer ________

B. actual range? Answer ________

C. predicted range? Answer ________

D. intercept point? Answer ________

6. Reproduce the appropriate weather symbols in the space provided.

A. Clear Answer ________

B. Snow Answer ________

C. Wind speed of 15 mph Answer ________

7. Reproduce the appropriate kill probability symbols in the space provided.

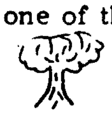
A. .25 Answer ________

B. .50 Answer ________

C. .75 Answer ________

D. 1.00 Answer ________

8. Which one of the following symbols represents a high explosive weapon?

A. 

B. 

C. 

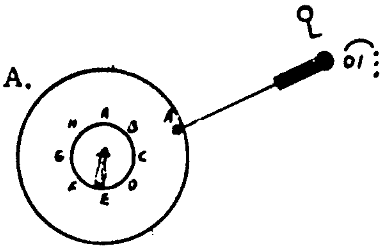
Answer ________

9. What is represented by the circles around the Philadelphia and Washington-Baltimore complexes?

Answer __________

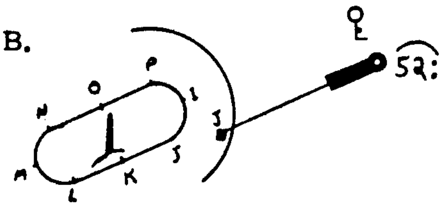
10. According to the Ground Rules, which weapon would you launch, given the following situations?

A.



Answer __________

B.



Answer __________

SYMBOL TEST FOR TABULAR--BLACK AND WHITE DISPLAYS

Applied Psychological Services
Science Center
Wayne, Pennsylvania

Name____________________________________ Date________________

1. What is indicated when a threat number begins with the numeral 5?

   Answer ______________________

2. What do the following symbols indicate?

   A. *N* Answer ______________________

   B. *H* Answer ______________________

   C. *L* Answer ______________________

3. What is indicated by the "actual range" value?

   Answer ______________________

4. What is indicated by the "predicted range" value?

   Answer ______________________

5. If you wanted to know the direction in which a threat was heading, where would you refer?

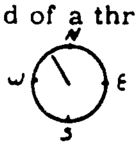
   Answer ______________________

6. If you wanted to know where a threat was located in reference to the complex, where would you refer?

   Answer ______________________

7. If you wanted to know the direction in which a threat will be heading in 15 seconds, where would you refer?

Answer ____________________

8. If the actual coor'd of a threat is given as NW and the wind direction is given as follows, 

is the wind in the direction of the complex? (yes, no)

Answer ____________________

9. What does ■ indicate?

Answer ____________________

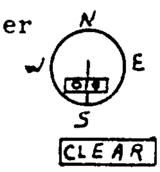
10. Describe the state of the battery M as given in the following situation?

Des.	Ready	Assigned
M	■	N

Answer ____________________

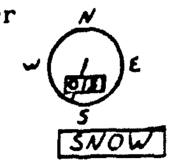
11. According to the Ground Rules, which weapon would you launch, given the following situation?

Threat 01 , Few , Range Predicted = 175 , Actual Range = 200 , Altitude = 25.0 , Actual Heading = 270 , Actual Coor'd = E , Predicted Heading = 270 , Predicted Coor'd = E , Intercept Point = 147 , Intercept Coor'd = E , Weather



Answer ____________________

B. Threat 52 , MANY , Range Predicted = 155 , Actual Range = 190 , Altitude = 37.5 , Actual Heading = 260 , Actual Coor'd = E , Predicted Heading = 260 , Predicted Coor'd = E , Intercept Point = 125 , Intercept Coor'd = E , Weather



Answer ____________________

APPENDIX E

QUESTIONS FOR COMMAND AND CONTROL SITUATIONS

Experiment II

QUESTIONS FOR COMMAND AND CONTROL SITUATIONS NO. 1

1. Which weapon should be launched against threat 11?

2. Which weapon should be launched against threat 09?

3. Which weapon should be launched against threat 53?

4. To which battery should threat 09 most probably be assigned?

5. To which battery should threat 53 most probably be assigned?

6. Which threat should be assigned next?

7. What is the overall probability of kill across all threats?

8. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?

9. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?

10. Which battery(ies), if any, selected an improper missile to launch?

11. Assuming a wind shift of 180°, for which threats would you select a different missile to launch? (Answer "None," if appropriate).

12. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

QUESTIONS FOR COMMAND AND CONTROL SITUATION NO. 2

1. Which weapon should be launched against threat 12?
2. Which weapon should be launched against threat 53?
3. Which weapon should be launched against threat 06?
4. To which battery should threat 06 most probably be assigned?
5. To which battery should threat 07 most probably be assigned?
6. Which threat should be assigned next?
7. What is the overall probability of kill across all threats?
8. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?
9. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?
10. Which battery(ies), if any, selected an improper missile to launch? (Answer "None," if appropriate).
11. Assuming a wind shift of 180°, for which threats would you select a different missile to launch? (Answer "None," if appropriate).
12. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

QUESTIONS FOR COMMAND AND CONTROL SITUATION NO. 3

1. Which weapon should be launched against threat 57?
2. Which weapon should be launched against threat 51?
3. Which weapon should be launched against threat 54?
4. Which weapon should be launched against threat 09?
5. Which weapon should be launched against threat 12?
6. To which battery should threat 54 most probably be assigned?
7. To which battery should threat 12 most probably be assigned?
8. To which battery should threat 51 most probably be assigned?
9. To which battery should threat 09 most probably be assigned?
10. Which threat should be assigned next?
11. What is the overall probability of kill across all threats?
12. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?
13. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?
14. Which battery(ies), if any, selected an improper missile to launch? (Answer "None, " if appropriate).
15. Assuming a wind shift of 180^{o}, for which threats would you select a different missile to launch? (Answer "None, " if appropriate).
16. Which threat(s), if any, should be assigned to more than one battery? (Answer "None, " if appropriate).

QUESTIONS FOR COMMAND AND CONTROL SITUATION NO. 4

1. Which weapon should be launched against threat 09?

2. Which weapon should be launched against threat 57?

3. Which weapon should be launched against threat 51?

4. Which weapon should be launched against threat 55?

5. Which weapon should be launched against threat 11?

6. Which weapon should be launched against threat 56?

7. To which battery should threat 55 most probably be assigned?

8. To which battery should threat 56 most probably be assigned?

9. To which battery should threat 57 most probably be assigned?

10. To which battery should threat 51 most probably be assigned?

11. To which battery should threat 11 most probably be assigned?

12. Which threat should be assigned next?

13. What is the overall probability of kill across all threats?

14. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?

15. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?

16. Which battery(ies), if any, selected an improper missile to launch? (Answer "None," if appropriate).

17. Assuming a wind shift of 180°, for which threats would you select a different missile to launch? (Answer "None," if appropriate).

18. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

QUESTIONS FOR COMMAND AND CONTROL SITUATION NO. 5

1. Which weapon should be launched against threat 08?
2. Which weapon should be launched against threat 13?
3. Which weapon should be launched against threat 05?
4. Which weapon should be launched against threat 09?
5. Which weapon should be launched against threat 55?
6. Which weapon should be launched against threat 01?
7. Which weapon should be launched against threat 54?
8. Which weapon should be launched against threat 12?
9. Which weapon should be launched against threat 52?
10. To which battery should threat 13 most probably be assigned?
11. To which battery should threat 05 most probably be assigned?
12. To which battery should threat 10 most probably be assigned?
13. To which battery should threat 03 most probably be assigned?
14. To which battery should threat 07 most probably be assigned?
15. To which battery should threat 12 most probably be assigned?
16. To which battery should threat 14 most probably be assigned?
17. To which battery should threat 55 most probably be assigned?
18. To which battery should threat 01 most probably be assigned?
19. Which threat should be assigned next?
20. What is the overall probability of kili across all threats?

21. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?

22. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?

23. Which battery(ies), if any, selected an improper missile to launch? (Answer "None," if appropriate).

24. Assuming a wind shift of 180°, for which threats would you select a different missile to launch? (Answer "None," if appropriate).

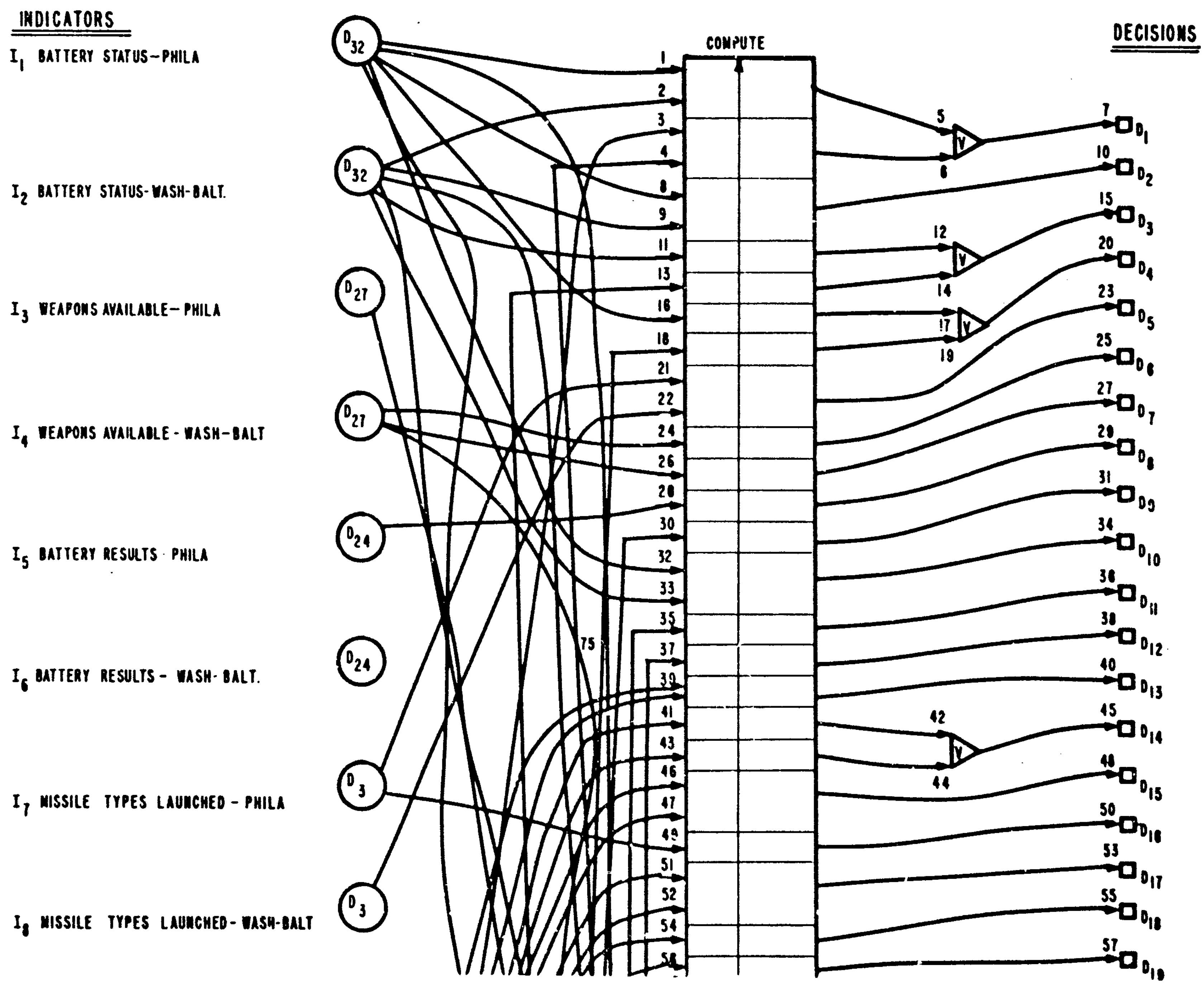
25. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

QUESTIONS FOR COMMAND AND CONTROL SITUATION NO. 6

1. Which weapon should be launched against threat 03?
2. Which weapon should be launched against threat 02?
3. Which weapon should be launched against threat 57?
4. Which weapon should be launched against threat 50?
5. Which weapon should be launched against threat 56?
6. Which weapon should be launched against threat 51?
7. Which weapon should be launched against threat 08?
8. To which battery should threat 56 most probably be assigned?
9. To which battery should threat 57 most probably be assigned?
10. To which battery should threat 02 most probably be assigned?
11. To which battery should threat 08 most probably be assigned?
12. To which battery should threat 03 most probably be assigned?
13. Which threat should be assigned next?
14. What is the overall probability of kill across all threats?
15. If both Philadelphia computers were to fail now, which threat would you assign first to the Washington-Baltimore complex?
16. If both Washington-Baltimore computers were to fail now, which threat would you assign first to the Philadelphia complex?
17. Which battery(ies), if any, selected an improper missile to launch? (Answer "None," if appropriate).
18. Assuming a wind shift of 180°, for which threats would you select a different missile to launch? (Answer "None," if appropriate).
19. Which threat(s), if any, should be assigned to more than one battery? (Answer "None," if appropriate).

APPENDIX F

SAMPLE DEI CALCULATION


INDICATORS
I1 BATTERY STATUS-PHILA
I2 BATTERY STATUS-WASH-BALT.
I3 WEAPONS AVAILABLE-PHILA
I4 WEAPONS AVAILABLE-WASH-BALT
I5 BATTERY RESULTS PHILA
I6 BATTERY RESULTS-WASH-BALT.
I7 MISSILE TYPES LAUNCHED-PHILA
I8 MISSILE TYPES LAUNCHED-WASH-BALT
COMPUTE
DECISIONS

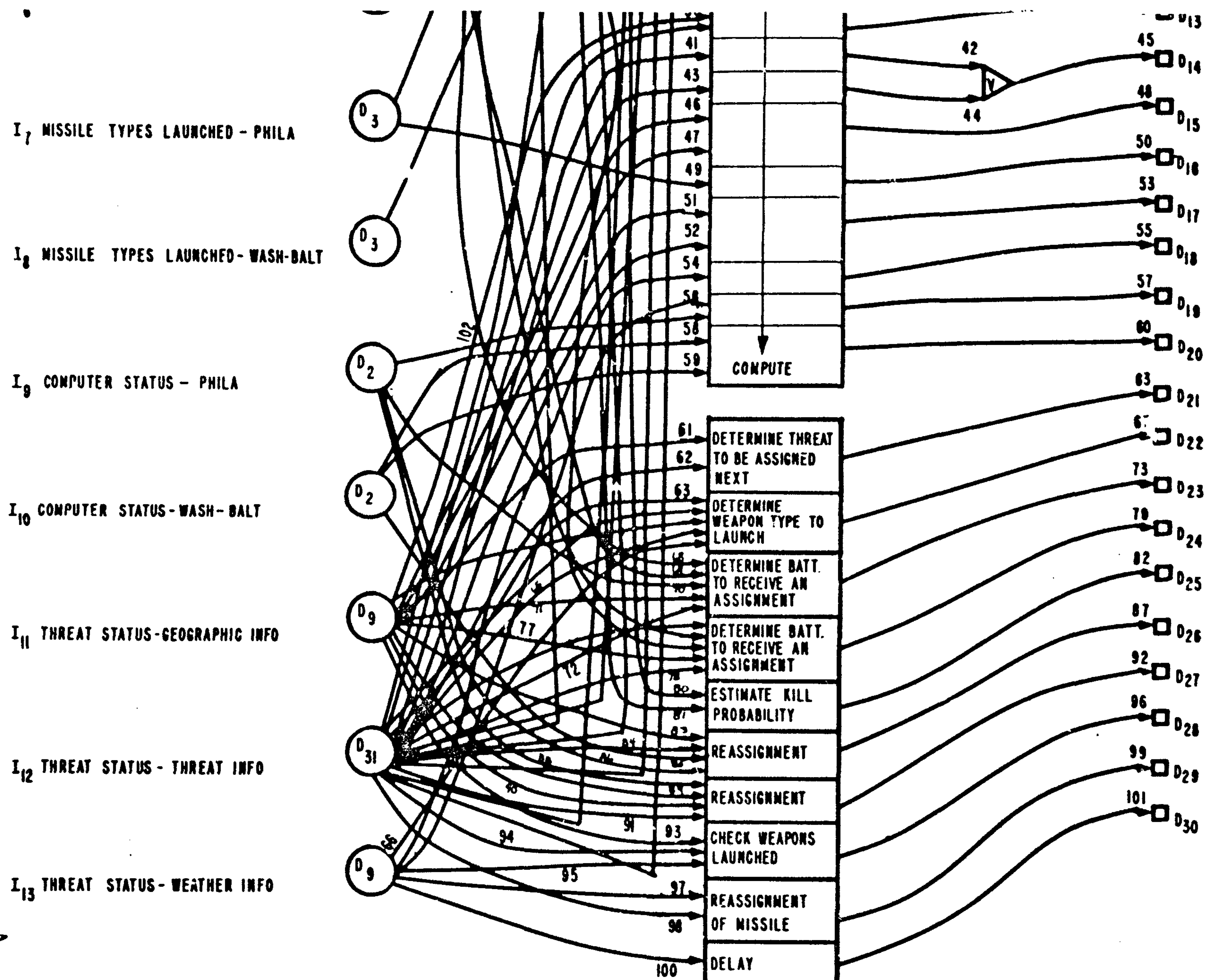


FIGURE F-1. TRANSFER CHART

DEI TRANSFER TABLE

LINK NO.	DISPLAY DIGITS	ACTION DIGITS	ABSOLUTE MISMATCH DIGITS (M)	LINK WEIGHTS (W)	LINK NO.	DISPLAY DIGITS	ACTION DIGITS	ABSOLUTE MISMATCH DIGITS (M)	LINK WEIGHTS (W)	LINK NO.	DISPLAY DIGITS	ACTION DIGITS	ABSOLUTE MISMATCH DIGITS (M)	LINK WEIGHTS (W)
1	1.98	—	—	2	37	2.63	—	—	0	73	1.15	—	—	1
2	1.98	—	—	2	38	.78	.00	.78	1	74	1.98	—	—	0
3	2.63	—	—	2	39	1.43	—	—	2	75	3.44	—	—	0
4	2.63	—	—	2	40	.78	.00	.78	1	76	.78	—	—	0
5	1.23	—	—	0	41	2.63	—	—	0	77	1.43	—	—	0
6	1.23	—	—	0	42	.78	—	—	0	78	2.63	—	—	0
7	1.23	1.11	.12	0	43	2.63	—	—	0	79	1.15	1.15	.00	1
8	1.98	—	—	0	44	.78	—	—	0	80	1.98	—	—	2
9	1.98	—	—	0	45	.78	.00	.78	0	81	1.98	—	—	2
10	1.23	1.04	.1[illegible]	1	46	1.43	—	—	2	82	.70	—	—	1
11	1.98	—	—	2	47	2.63	—	—	2	83	1.43	—	—	0
12	.95	—	—	0	48	.78	.00	.78	1	84	2.63	—	—	2
13	2.63	—	—	2	49	2.33	—	—	0	85	.78	—	—	0
14	.95	—	—	0	50	.48	.48	.00	1	86	.78	—	—	0
15	.95	.30	.65	0	51	1.43	—	—	0	87	.70	—	—	1
16	1.98	—	—	0	52	2.63	—	—	2	88	.78	—	—	0
17	.95	—	—	0	53	.78	—	—	1	89	.78	—	—	0
18	2.63	—	—	0	54	1.57	—	—	2	90	1.43	—	—	0
19	.95	—	—	0	55	.78	.78	.00	1	91	2.63	—	—	0
20	.95	.00	.95	0	56	1.57	—	—	2	92	.70	.70	.00	1
21	2.33	—	—	0	57	.78	.78	.00	1	93	1.43	—	—	0
22	2.33	—	—	0	58	.78	—	—	2	94	2.63	—	—	0
23	2.15	2.09	.06	1	59	.90	—	—	2	95	1.57	—	—	2
24	3.44	—	—	0	60	.70	.40	.30	1	96	1.23	1.23	.00	1
25	2.00	1.94	.06	1	61	1.43	—	—	2	97	1.57	—	—	2
26	3.44	—	—	0	62	2.63	—	—	0	98	2.63	—	—	0
27	.95	.60	.35	1	63	.78	—	—	1	99	.78	.78	.00	1
28	3.38	—	—	2	64	1.43	—	—	0	100	2.63	—	—	2
29	.95	.95	.00	1	65	2.63	—	—	2	101	.78	—	—	1
30	2.63	—	—	2	66	1.57	—	—	2	102	2.63	—	—	2
31	.78	.00	.78	1	67	.48	—	—	1	103	2.63	—	—	2
32	1.98	—	—	2	68	1.92	—	—	0	104	2.63	—	—	2
33	1.98	—	—	2	69	3.44	—	—	0	105	2.63	—	—	8
34	.48	.00	.48	1	70	.78	—	—	0	BOXES	34			136
35	2.63	—	—	2	71	1.43	—	—	0	TOTAL			7.24	224
36	.78	.60	.18	1	72	2.63	—	—	0					

DEI Worksheet

1. $1 + \Sigma_w$ (link weights, see Transfer Table) $= 1 + 224$ $= 225$

2. $(n + m)_u$ (number of used indicators and decisions, see Transfer Chart) $= 42$

3. $(n + m)_t$ (total number of indicators and decisions, see Transfer Chart) $= 43$

4. N (total number of links, see Transfer Table) $= 105$

5. Q (total number of indicator and decision parts, see Transfer Chart) $= 235$

6. n_o (number of ▭ and ▷, see Transfer Chart) $= \underline{38}$

7. $(Q + n_o)$ $= \underline{\underline{273}}$

8. $N(n + m)_t\ (Q + n_o) = (105)\ (43)\ (273)$ $= 1,232,595$

9. $\sqrt{N\ (n + m)_t\ (Q + n_o)}$ $= 1,110$

10. $\Sigma\ |M|$ (absolute mismatch digits, see Transfer Table) $= 7.24$

11. $1/4\ \Sigma\ |M|$ $= 1.81$

12. $\exp\ (-\ 1/4\ \Sigma\ |M|\ )$ $= .164$

$$DEI = \frac{(n + m)_u\ [\ \exp\ (-\ 1/4\ \Sigma\ |M|\ )\ ]}{(1 + \Sigma_w)\ [\ \sqrt{N\ (n + m)_t\ (Q + n_o)}\ ]}$$

$$= \frac{(42)\ (.164)}{(225)\ (1110)}$$

$$= \frac{6.888}{249,750}$$

$$= .0000276 \times 10,000$$

$$= .276$$

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13 ABSTRACT

The validity of the Display Evaluative Index technique was investigated in two separate studies. Both studies indicated adequate predictive validity for the technique. The ability of the technique to predict "decision making" was found to be superior to its ability to predict "information extraction" processes. Generally, it was found that pictorial type displays are superior to tabular displays for "decision making;" no difference seemed manifest between the two display types for "information extraction." Adding appropriate color coding seemed to augment the ability of the user to employ display information. As fact density increased, display decision making scores decreased.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Display Evaluation						
Human Factors						
Information Transfer						
Quantitative Methods						
Equipment Assessment						

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